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ARTHUR MARSHALL ARTER, A.M.I.C.E., M.I.A.E.,
President of the Society of Engineers (Incorporated), 1923.

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EDITED BY

A. S. E. ACKERMANN, B.Sc. (Engineering).
A.C.G.I., M.Cons.E., A.M.Inst.C.E.,
SECRETARY.

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Monday, February 5, 1923.

INAUGURAL MEETING FOR THE YEAR 1923.

At the Inaugural Meeting it was announced with regret that the President for 1923, Mr. Arthur Marshall Arter, A.M.I.C.E., M.I.A.E., was unable to be present to deliver his Presidential Address owing to serious illness. Mr. T. J. Gueritte, the retiring President, presented the Premiums awarded by the Council for papers read during 1922, as set out at pp. 292 and 293 of Journal No. 4, 1922.

Mr. A. Stewart Buckle proposed a vote of thanks to Mr. Gueritte for his services as President during the year 1922. This was seconded by Mr. C. H. J. Clayton and carried by acclamation.

Monday, February 5, 1923.

MR. T. J. GUERITTE, PAST-PRESIDENT,
IN THE CHAIR.

PRACTICAL NOTES ON INSPECTION.

By A. Collis-Brown, A.M.S.E.

At the outset the author wishes it to be understood that in the compilation of these notes he had in mind inspection as applied to a medium sized plant producing internal combustion engine details, or parts of a similar nature. It will no doubt be agreed that methods of inspection desirable and applicable in these circumstances are not only inadvisable, but most probably impracticable when considered in conjunction with work of a totally different character.

The efforts demanded of manufacturers during the late war for increased speed and efficiency led to a greatly accelerated advance in organisation, and by no means the least to feel the effect was the subject of inspection. It is no longer regarded in the light of a necessary evil, but rather as an important accessory to, if not yet credited with, being an actual producing department.

Two Systems.—There are, broadly speaking, two methods of conducting an inspection department; either by the "sectional" or "centralised" system. Briefly defined, "sectional" inspection consists of allocating at least one inspector to each section of the machines in the machine shop, and to each other department where such services are required; the inspection being conducted by the inspector on the spot. The "centralised" method, which is the more popular, involves an inspection department, or a view-room as it is often styled, situated in a central position as accessible as possible to all departments sending component parts to be inspected.

The Two Systems Compared.—Sectional inspection necessitates a considerably greater outlay in equipment and staff, but saves time otherwise used in transporting the parts from the particular section to the view-room. It also prevents the congestion of work which may occur in a central view-room. These are dubious gains indeed when compared with the smaller expense and other advantages of the centralised method. On the central system all parts are inspected at the one place which, if possible, should be located with the progress department's stores adjacent, to which, following inspection, all O.K. parts proceed and whence they are re-issued for the next operation. By this means the work of the progress department is considerably simplified and the amount laid out in inspection equipment is a minimum. A fault which arises with this method is the more or less continual stream of operatives who, having set up their machines afresh or for some other reason, are desirous of having their " first-one-off " or sample part tried over. This must be prevented, and can be done where the machine shop is compact by locating a reliable inspector with a small bench and the necessary tools in a convenient central position to act as far as possible as a general source of information and to try over any sample parts. A 12″ vernier caliper is all the equipment he will require in the majority of cases. Other advantages of this innovation are that it reduces the interruptions occasioned to other inspectors working in the view-room, and the very fact of an inspector being within easy reach, operatives will query any point about which they may be in doubt, whereas, were circumstances otherwise, they would continue working without taking this precaution, trusting to luck that they may be right. Much time of the operative is also saved and the possibility of scrap being produced reduced.

Inspectors' Qualifications.—The class of person to be employed as inspectors is a point of vital importance. In the opinion of the author, men intended as inspectors for the class of work under consideration should be decidedly above the average intelligence and capable of acting on their own initiative, inasmuch as to some extent they must on certain occasions use their discretion in deciding whether a part, though not strictly in accordance with the drawing, is usable or scrap. Where there is still doubt the chief inspector must be consulted for a final ruling. Inspectors must also be familiar with the layout of the different parts ; their subsequent use and the types of jigs and fixtures in use in the shop. Actual drawing office experience would also be an advantage. Only by practice can a man become proficient in the use of verniers and micrometers, and kindred precision instruments which depend almost entirely upon a cultivated sense of sight and touch. It is admitted that a large proportion of the work can be carried out by the use of snap and plug limit gauges, but where a part has inadvertently been made a shade different, either larger or smaller as the case may be, to the limits allowable, then some form of measuring instrument must be used in order to ascertain the exact amount of the discrepancy.

In the employment of unskilled or semi-skilled labour in this capacity, there is always a considerable amount of work delayed awaiting the chief inspector's decision, and this fault is intensified by the reluctance of this class of labour to take the slightest responsibility. It is not proposed to make any definite statement here as to the virtues or disadvantages of their attitude in this matter, but it is well within the bounds of possibility that it is an advantage.

Inspection of Material.—The inspection of the raw material is a most important matter, but to deal at all adequately with this branch of the subject involves a knowledge of metallurgical chemistry and must therefore be considered as being outside the scope of this paper. In the ordinary run of things it is not customary or necessary for a manufacturing company to install a laboratory or employ a chemist to analyse and determine the qualities of the ingredients of the metals to be used in the manufacture of its products, because if purchased from firms of good repute, they may be relied upon to supply materials consistently to the specifications required. In view of this, then, steel bars, etc., may be accepted so long as their distinguishing marks are in accordance with the invoice. Where castings are concerned, these should be thoroughly inspected immediately upon delivery to see if there are any serious flaws and whether they will clean up in machining. Any maker's scrap so discovered will thus get no farther than the receiving department. Where considerable quantities of castings are involved, it is sometimes considered advisable to send an inspector to the foundry of the outside contractor to do this work on the spot and so save any superfluous cartage.

Inspection of Work in Progress.—Except on rare occasions it is not necessary to inspect the work of the marker-out; where more than one is employed it is customary for them to check their work amongst themselves. Every part should be inspected after every operation, and where practicable stamped by the inspector with a private stamp, with which each inspector should be supplied, so that any faulty work can be readily traced to the responsible party. At the same time great care must be taken with the location of the inspector's mark, primarily because it is possible to do considerable damage to a part by carelessness in this matter. Secondly, cases have been known where operatives working on a piecework basis have machined the mark out and submitted the part for inspection a second time, thereby being credited with work they have not actually done. This latter possibility can, of course, be counteracted by efficient organisation. When the part concerned is a small one and being turned out in quantity on an automatic lathe, the first, say, half-a-dozen should be inspected and similarly when any of the tools are changed. Finally, when the required number is brought to the view-room they should be carefully looked over and the checking of the dimensions of ten per cent. should suffice.

When a tool-room is maintained for the making of gauges and jigs, these have to be inspected, and in many cases this work falls to the general view-room. Obviously the utmost accuracy must be observed here because the accuracy of the work in conjunction with which the tools or jigs are to be employed depends to a large extent upon it, Where the size of the works warrants it there should be a special view-room for this purpose.

Inspection of Tools and Gauges.—All tools, gauges, etc., should be tested at frequent intervals according to their type and the amount of use they receive. All micrometers should be tested at least once a week and verniers similarly. Plug and ring gauges, gap and plate gauges when in constant use should be tested frequently. Broadly speaking the life of gauges used in the inspection department is twice that of similar gauges in use in the shop. In the former case the inspector uses his gauges with all reasonable care. In the latter the operative is usually on piecework and his whole idea is to turn out as many parts as possible in a given time. He accepts no responsibility for the inaccuracies of his gauges.

Under no consideration should inspection gauges or instruments allocated to the view-room staff ever be lent out. Corresponding tools for general works use should be stocked in the tool stores and be procurable on check.

Gauge Life.—To determine the length of life of a gauge is a difficult matter and at the best the answer will be but a very rough approximation. There are many things to be considered in relation to this question, each of which may have a direct bearing upon the result. For instance :—of what material is the gauge made ; under what conditions is it used :—in the shop ; in the inspection department, or is it merely used for reference ? Furthermore, on what class of material is it used ; cast-iron, steel, brass, etc. ; and on what operation ; rough turning, finished turning, grinding, etc. ? Also, and by no means of least importance, what grade of finish has been obtained on the measuring faces and has any tolerance been allowed for wear on the gauge ?

Materials for Gauges.—There are several materials used in the manufacture of limit gauges, including tool-steel, cast and malleable iron, but so far as the author is aware there is no hard and fast rule governing the use of the materials mentioned. For general use, tool-steel, hardened and ground and finally lapped, gives excellent service. The majority of gauges are hardened, with the exception of screwed plug gauges and such as are required to have but a very short life. Drop forgings are common practice for small snap gauges and cast steel for large ones of this type. Makers of the adjustable type snap gauges often use cast-iron for the frame as this has the advantage, that if subjected to rough treatment in use, the frame will break rather than distort.

Working Conditions.—Obviously a gauge used for reference is not likely to be subjected to as much wear as one used in the inspection department and similarly a view-room gauge should obtain better treatment than one used in the shop.

The next factor under consideration is the material and operation on which it is used. Cast-iron has been found to be much harder on gauge life than either brass or steel, and similar results are attributed to aluminium. As regards the operation, or state of the material on which it is used, it is not surprising to find that gauges used on roughing operations wear down quicker than similar gauges used on a smooth surface. So great is the influence of this factor on the life of a gauge that to say that a gauge used on rough turned work has but half the life of a similar one used on a smooth surface would be no exaggeration.

Finish on Measuring Faces.—As is generally understood, an apparently perfectly smooth machined surface magnified is in reality very lumpy. The more smooth the surface means in non-technical language, the " lumps " are more minute and more numerous. This being the case it will readily be appreciated that the smoother the measuring faces are, the longer the life of the gauge.

Tolerances on Gauges.—It is always advisable to make gauges with as much tolerance for wear as possible, but this is governed by the amount of tolerance on the work for which the gauge is required. Usually .0001 inch at least could be left for wear without affecting the interchangeability of the work. By recognising the importance of the subject of wear in connection with gauge manufacture much expense can be curtailed. With this object plug gauges should be made slightly large and snap gauges similarly smaller to ensure as long life as possible. For example, where the limits on the work are ±.001″ the limits on the gauge might be ±.0002″. On work of a more accurate nature where the limit is, say, ±.0003″ the limits to which the gauge must be made are correspondingly reduced to ±.00006″. As will be noticed from the foregoing examples the limits on the gauges are one-fifth of the limits on the work.

Plug, Ring and Snap Gauges.—There are three groups into which gauges can be divided, reference, shop and inspection gauges. The former, sometimes termed standard gauges, are kept for such purposes as setting adjustable snap gauges, micrometers and other instruments. The reference plug gauge is usually single-ended and to facilitate increased accuracy is often unhardened. These gauges should be used with great care therefore and never in the actual inspection of parts. By shop gauges are meant the limit plug and snap gauges made for the different jobs and used on the various operations in the shop.

Inspection gauges, as the term clearly implies, are similar to shop gauges, but are used solely by the inspection staff. The limits on these gauges are usually the same as those on the shop gauges.

Plug gauges are made in two forms ; in the one case with the " not go " diameter at one end and with the " go " diameter plug at the other end of a common handle. The " go " being made twice as deep as the " not go " plug prevents any possibility of the wrong end being worked to. The other style of limit plug gauge has both " go " and " not go " diameters situated at one end of a common handle. One of the disadvantages of this type is that the " go " portion of the gauge cannot, in many cases, pass right through the hole. Secondly it is not so readily adaptable to another job as the double-ended or dumb-bell type of plug.

The ring gauge has but a limited sphere of operation and is supplanted to a considerable extent by the snap gauge. For instance, it is not convenient for a turner making a spindle involving several diameters to be continually removing it from between the lathe centres to try a ring gauge on the spindle. This would also involve the use of two rings, one a " go " ring and the other a " not go." In this instance the snap gauge is undoubtedly the better to use.

Snap or gap gauges are made in a variety of forms ; those for use as standards having but a single end and of course only one dimension. There is also the single-ended limit snap gauge, having one anvil common to the two dimensions and the other anvil unequally divided into two. The distance between the greater and forward anvil and the common anvil is the " go " dimension, and the " not go " dimension is of course between the smaller and the common anvil. The commonest form is the double-ended snap gauge which has one end made to " go " and the other end " not go." There have been several devices brought forward to prevent distortion to snap gauges which may be caused by the gauge being passed over the work with unnecessary harshness and knocking the inside of the gauge. These devices usually consist of some type of buffer, generally of rubber, to take the impact. Appreciable protection can be obtained by binding the part with suitable string or cord. This has the additional advantage, when the gauge is used by an oily hand, of affording a better and easier grip.

Finally there is that highly useful tool, the adjustable snap-gauge. This is of the single-ended type and provided with four anvils, two of which are adjustable by means of a fine thread. There is a locking device to prevent the setting being altered when the gauge is in use. The amount of adjustment possible on each gauge is not more than half-an-inch, which means that one sized gauge may be set to gaps ranging between 1″ and 1½″ ; the next size of gauge will range from 1½″ to 2″, etc. The frames are made of cast-iron for reasons previously given. Gauges of this type manufactured by Newall's are so well known that it is no uncommon thing to hear any snap gauge which is adjustable, irrespective of make, referred to as a "Newall gauge"!

Johansson Blocks.—For use in setting these gauges a set of Johansson reference blocks are invaluable. These blocks are made of steel, rectangular in shape, and all opposite faces are parallel to a fine degree of accuracy. Each block has its size stamped on it and by putting various sized blocks side by side it is possible to compile any dimension between certain extremes in increases of .0001″.

Plate Gauges.—By the term plate gauges the author refers to gauges made from sheet steel, which include templates, profile gauges and combination gauges. None of these is devoid of the disadvantage which is also common to the ordinary plug and snap gauges in that they do not show to what extent a dimension may be in error. Consequently suitable indicating gauges must be resorted to for this purpose. However, in many cases where plate-gauges are employed the tolerance is more or less generous, so that there is but little excuse for serious errors.

Inspecting Gears.—If gears are required to run at high speeds under heavy loads with the least possible noise, it is essential that they be carefully tested and inspected for concentricity, diameter, centre distance, tooth shape and pitch diameter. In motor-car construction the elimination of noise is of primary importance and a differential gear or a transmission gear when running in the chassis may sound not unduly noisy until a body of the closed type has been fitted to the chassis. This often magnifies the sound emitted by inaccurate gears to such an extent that the offending component must be changed for a better one. In testing bevel gear blanks it is important to see that the angular face, which will be eventually the tops of the teeth, is in correct relation to the hole ; that the angle is correct and that the rear face is at right angles to the axis. The usual way of trying these angles is by means of the bevel protractor, but where considerable quantities are involved plate gauges are preferable.

For measuring the thickness of gear teeth a simple template made from sheet steel having a slot cut in one end the width of which is equal to the chordal thickness of the tooth at the pitch line and having a depth corresponding to the height of the tooth from the pitch line is often used in the shop in preference to the gear-tooth vernier. The vernier would be used by the inspector for testing these dimensions.

In gear inspection the three most important points to receive attention should be the tooth profile, pitch diameter and centre distances. For gears used in the transmission systems of motor cars which are of involute form an endeavour should be made to hold the involute curve to a tolerance of ·0005″. If the teeth are ground a similar degree of accuracy should be aimed at as regards the spacing of the teeth. For all general purposes a variation not exceeding ·002″ gives satisfactory results.

Gear Testing Fixtures.—Numerous fixtures have been evolved from time to time for the purpose of accurately gauging the variation between gears of the pitch diameter, centre distance and concentricity. The majority of these fixtures are common as to their fundamental principles, thus :—they each consist of a bed on which are two slides, one fixed and one floating ; on each slide is a vertical stud. On the stud attached to the fixed slide is fitted an accurately machined master gear ; the gear to be tested being put on the stud on the movable slide. These two gears are brought into mesh and held there by some convenient means such as a coil spring of suitable strength, so attached as to pull the movable slide towards the stationary one. Upon rotating the gears, any movement of the movable slide is shown on some form of dial indicator, or other suitable multiplying lever arrangement, with which the slide is in constant contact, thus showing any variation in the concentricity of the gear. If it is desired to test the centre distance in addition to the concentricity, a scale is provided one end of which is anchored to the fixed slide and the remainder is free to move in conjunction with a vernier attached to the floating slide. By this means the moving slide is set to the required centre distance and upon rotating the gears any variation can be read off on the indicator previously referred to. For hand rolling of gears, jigs with fixed centres made to accommodate standard mating gears are very useful. Mating gears should give a perfectly smooth satisfactory roll by hand on this type of testing jig, and at the same time it is convenient for checking the amount of backlash, which should be sufficient to eliminate any tendency towards jamming.

Testing Involute Curve of Profile.—Hand rolling with a mating gear is also often resorted to for determining whether the involute profile of the teeth is correct or not simply by the "feel." A considerable amount of experience is necessary by the inspector before proficiency is reached in this method. Divers fixtures have been produced for testing the accuracy of gear tooth profile to within very fine limits, but there appears to be no recognised standard machine for this work and consequently any firm requiring such a fixture makes one to suit its own requirements. So long as the teeth are bearing evenly along their faces, and have successfully passed the other tests, it is hardly likely that there is any serious error on the profile.

Testing Gears for Silence.—Both spur and bevel gears should be tested finally for silence in running. Except that the type of fixture is necessarily different the principle of the test is identical for both types. When testing a spur gear it is usually mounted on a mandril held between centres and parallel to a shaft on which is mounted the driven gear and a brake-drum. This shaft and its bearings complete are made movable to vary the depth to which the gears mesh and also to accommodate gears of varying diameters. The gear to be tested is rotated at varying speeds, usually by belt and pulley driving the mandril, and under a variety of loads applied to the driven shaft. The various grades of noise produced are closely listened to by the inspector, who from experience can readily diagnose the cause of sounds foreign to the smooth humming of satisfactory gears.

Inspecting Screw Threads.—Many firms find it a better proposition to purchase their nuts, bolts, studs and other small screwed parts from outside rather than manufacture them themselves, and such a policy is rather to be encouraged than not, for the cost of installing and running the plant necessary for producing a limited quantity of first-class parts of this nature is not an inconsiderable item.

Theoretically there appears to be five elements of a screw thread which must be accurate before it can be pronounced as satisfactory. The elements referred to are as follows :—outside diameter ; pitch diameter ; root diameter ; pitch ; angle of thread. Commercially the three elements of importance for producing a satisfactory thread are the pitch, the pitch diameter and the angle. It will thus be seen that the outside diameter does not figure as an element of importance. In fact, all things being equal, it is better that a bolt should be a shade undersize in this respect.

Tolerances.—Standardization of tolerances for the various elements of screw threads is a difficult problem, but considerable attention has been given to the subject by the Engineering Standards Committee of this country with the result that certain tolerances have been established. The following formulæ give the tolerances for Standard Whitworth threads :—

When D = nominal dia. of thread in inches then :—
tolerance on outside dia. of bolt $= -(\cdot 0035 \times \sqrt{D})''$
,, ,, root ,, ,, ,, $= -(\cdot 0045 \times \sqrt{D})''$
,, between bolt and nut $= +(\cdot 001 \times \sqrt{D})''$
,, on outside and root dia. of nut
$= +(\cdot 0035 \times \sqrt{D})''$

The tolerance established on the nut must be added to the clearance between the bolt and nut. The maximum permissible error in pitch is determined by the following formula, the thickness of the nut being assumed to be equal to the diameter of the bolt :—

Tolerance in pitch per inch of length of thread in nut =

$$\pm \frac{\cdot 0025}{\sqrt[4]{D}}$$

Applying the above formula to a ¼″ bolt the result is $\pm \cdot 0035''$ which is equal to rather less than $\pm \cdot 001''$ permissible error in the length of thread in the nut. When determining the tolerance to be allowed on the pitch diameter, an amount corresponding to the maximum error tolerated in pitch should be included. This compensation has been embodied in the following formula :—

Tolerance on pitch dia. $= \cdot 005\sqrt[4]{D^3}$

The amount of tolerances permitted on the angle of the threads are as follows :—

Nominal dia. ¼″ to $\frac{9}{16}''$ $\pm 1\cdot 5^{\circ}$
,, ,, ⅝″ to 2⅛″ $\pm 1\cdot 0^{\circ}$
,, ,, 2¼″ to 3″ $\pm 0\cdot 5^{\circ}$

The coarser the pitch of the thread, the smaller is the amount of error permissible in the angle.

Gauging Screw Threads.—Gauges for screw threads of the plug and ring type cannot be relied upon in a hard and fast manner to give a true indication of the state of affairs prevailing. For instance, a bolt having the outside diameter of its threads full size would feel to be a nice fit when tried with a screwed ring gauge, but at the same time the angle of the thread might be seriously inaccurate without affecting the fit of the gauge. It is therefore imperative that the different elements shall be tested separately. The three-wire method has long been regarded as the most satisfactory method of measuring the pitch diameter and is perhaps too well-known to brook much comment here beyond to remark that if some special fixture is made to act as a third hand to the inspector the job is much less of a juggle than it is usually imagined. In spite of some slight difficulty in manipulation, the three-wire system is superior to the simpler one-wire method inasmuch as the latter involves the outside diameter of the bolt.

The angle and pitch may be tested by means of sheet steel thread gauges of sufficient length to show up any inaccuracy of the pitch, and, if examined when in position against a light background, any appreciable variation in the angle can be seen readily. To inspect the angle of screwed plug gauges where greater accuracy is required, the following is an improved method. The gauge to be tested is held between centres, and a cone-pointed rod held in a tool-rest at right angles to the axis of the gauge is brought up to the gauge with its point resting between the threads. This point has been accurately ground to an angle corresponding to the included angle of the thread and similar rods to slightly varying angles are used to determine to what extent, if any, the angle is inaccurate. A light background is used to observe the fit of the pointed rod in the thread angle and a magnifying glass might be used to advantage.

Limit, Tolerance, Clearance.—The progress made between the days when one part was made to fit another with which it was destined to be assembled, to the methods in vogue to-day, when parts are made within predetermined limits and interchangeable one with another has been, as it should be, comparatively slow. However, slow, steady and sure progression is infinitely preferable and decidedly more likely to have lasting and beneficial results than any violent departure from the orthodox.

There are two ways of establishing a limit system, which is the basis of producing interchangeable parts, but the initial cost is more or less a common factor—high. It would obviously be a mistake to regard this factor from a narrow view point. For example, it will doubtless be admitted that it requires a high grade mechanic to make large numbers of parts exactly alike without any limit system, whereas a much less skilled man can turn out similar work to an interchangeable standard, with the aid of a system of limits. Further, much fitting is eliminated and in certain cases abolished altogether. The quantity of scrapped parts is also considerably reduced by the proper application of such a system. When adopting a limit system either the hole or the shaft must be taken as a basis and the more common practice is the former.

Owing to the lax way in which the terms limit, tolerance and clearance are often used, the following definitions are given in order to avoid confusion.

Limit :—The amount permissible above or below the nominal size. A two inch hole might be dimensioned thus :—2″ ± ·0005″ indicating that it may be ·0005″ above 2″ or .0005″ below 2″.

Tolerance :—the difference between the maximum and the minimum sizes. Using the same example, the tolerance would be ·001″.

Clearance :—the difference between the shaft and the hole, of which there are three grades, maximum, nominal and minimum. Employing the same example and a shaft which has to be a running fit in the hole has a diameter of 1·998″ ± ·0005″. This gives a maximum clearance of ·003″, a nominal clearance of ·002″ and a minimum one of ·001″.

When the question arises of setting limits on parts of an interchangeable nature it is a great mistake to set the limits any finer than necessary inasmuch as by so doing the production costs are increased.

There are various ways of stating the limits on drawings each of which has its particular advantages, but whatever mode is adopted it is advisable to keep rigidly to that method and so avoid much unnecessary confusion. One of the most expedient and clearest methods is to state the nominal size and indicate the limits by a single figure preceded by the plus or minus sign. That the figure represents thousandths of an inch being understood; thus 2.250″ $^{+2}_{-1}$ No dimension should be given without stating the limits, because one of two things inevitably happens, either the operative wastes time in making to the exact size, or he assumes that the dimension is of negligible importance and that anything within a quarter of an inch will suffice.

The position of the inspection department might be likened to that of a buffer state and unfortunately its neighbours often display an aggressive attitude towards it. It is deplorable that there still exist what might be termed interdepartmental wars :—when the machine shop tries to get the tool-room on the mat ; or the fitting department endeavours to take a rise out of the machine shop and the view-room is conducting a fierce defensive campaign continually. In such circumstances it is clear that the inspection department must be distinctly separate in its administration from any other department and subordinate to none. The type of strife referred to not only creates temporary ill-feeling between departmental heads but its effects are felt by every man in the departments concerned and the inharmonious atmosphere so created cannot but react detrimentally upon the progress chart.

Inspection Department—Private.—In conclusion, the author would like to draw attention to the fact that it is essential that the view-room should not be made a thoroughfare or yet a place of refuge for all and sundry. The following notice prominently displayed might be beneficial in combating the latter nuisance ; " If you have time to spare don't spend it with one who hasn't." This is preferable to the injunction of trans-Atlantic origin, " Keep out—this means you ! "

Discussion.

Mr. Geo. A. Becks, A.M.I.C.E., F.S.E., expressed a small disappointment because the paper was limited to inspection operations in connection with only fine mechanical repetition work. He had hoped, from the title, that the larger ground of engineering inspection might have been referred to, but it was noticed that the author had safeguarded himself at the outset by defining the limitations, so that it behoved the members to confine themselves within the same limits.

The author did not appear to make any reference to the effect of temperature which, when reading of ·0001″ were referred to, was not by any means immaterial, e.g., the speaker had been unable to insert standard length gauges between the anvils of a measuring machine after having held them for a few moments in his warm hand, although when cold, they had fitted exactly. It was observed that the author referred to winding cord round the gauges for another purpose, but the effect would be beneficial from a heat non-conducting point of view.

The speaker had heard of a case during the war in which some material that was rejected on account of being too small, during a cold spell, was laid aside and was accepted when the weather became warmer.

The speaker was not satisfied it had been made sufficiently clear in the paper that the maximum diameter of a plug gauge or a part which entered a hole must be less than the minimum diameter of the hole, as it was obvious that one part made to high gauge would not enter another part made to low gauge when the variation was the same either side of the absolute figure. It was usual, he thought, that there should be a difference of half a thousandth between the maximum of the one and the minimum of the other, so as to permit assembly.

There was no doubt that the standard of workmanship had been raised throughout the country by the rigid inspection demanded during the war, but mechanics did not yet appear to understand the decimal system, for although a turner would declare he could work to $1\frac{5}{8}''$ exactly he would decline to produce work to 1·625″ with the same accuracy.

And it was probably chiefly due to this ignorance, the speaker suggested, that the interdepartmental war referred to by the author were occasioned.

The author had given one of the most detailed papers, and one it had been a pleasure to listen to, the chief fault being that he had gone into the matter so thoroughly that there was little left to discuss.

Mr. Hal Gutteridge, A.M.I.Mech.E., M.I.E.I., congratulated the author on his excellent paper, the subject of which concerned all engineers, and particularly those engineers who, like the speaker, were in practice as inspecting engineers.

In discussing the testing screw threads the author did not mention the projected light method for testing male screw threads by comparison with a standard thread. This method is used extensively for accurate testing of the pitch, angles, depth, height and formation of threads by comparing the magnified shadow of the specimen with that of a standard screw thread magnified the same amount, or with a suitable diagram inscribed on the screen. By adjusting the position of the specimen the shadows can be brought together and any inaccuracies can be easily detected. This method has the advantages that it is quick and accurate even with small screw threads.

The knowledge and understanding of methods of inspection and manufacture is an important part in the training of engineers and is absolutely essential in the case of designers and those engineers whose duty it is to write specifications. With this knowledge a design or specification becomes a living thing, which the inspecting engineer when he comes to interpret its contents, can accurately turn into its material equivalent of a sound working job.

Mr. Francis R. Wade, M.I.M.E., M.I.Struct.E., M.I.A.E., M.I.E.I., said he would like—on behalf of the Institution of Engineering Inspection—to thank the Society of Engineers for the cordial invitation to the members of his Institution to attend the meetings. He could assure them that they considered it a great privilege to be allowed to join in the discussions, and on behalf of the Council of the I.E.I. he extended to all members of the Society of Engineers a similar invitation to attend the Institute meetings at the Royal Society of Arts.

The paper was one which was much in accord with the aims and objects of his Institution. The author appeared to have dealt thoroughly with the vital necessity of introducing standardised inspection in the various processes of manufacture, and had indicated where several pitfalls lay and how to avoid these difficulties. He would be glad if the author could have given more details and discussed the various values of percentage inspection as compared with individual examination, but he realised that in the space at the author's disposal this would have been impossible.

They could not lay too great stress upon the importance, from the industrial point of view, of individual inspection of the components as they passed through the various stages of manufacture. The craftsmanship of the country to-day was much inferior to what it was some 30 years ago, partly due to the introduction of single purpose labour-saving machines, and largely due to the terrible effects of the war, from which we should not recover for many years to come. It therefore behoved the English manufacturer to see how he could raise the standard of his products, and at the same time be able to compete with the markets of the world. He submitted that this could be done by great care and examination of the processes of manufacture of the components which go to make the whole, before they arrived at the final state of a complete machine. Not only would such examination greatly strengthen and improve the quality of the work, but it would also save large sums of money in the actual manufacturing operations, for to allow a component which was defective to be assembled into a complete article, only to be discovered when the whole was finished, was one of the most grievous mistakes that could occur in engineering work.

He had had the good fortune to be intimately connected with the photometric gauge and the examination of screw threads during the war, and it was perfectly wonderful how accurately external threads could be gauged and criticised by that method. It mattered little how small or how large the thread of the gauge was if the quantities sufficiently justified the use of this apparatus, and the result was almost always satisfactory.

Mr. H. Bath Spencer, M.I.Mech.E., A.M.Inst.C.E., M.I.E.I., said his experience in the Inspection Department of the Ministry of Munitions during the War had been mainly administrative, but he had seen enough of works inspection and gauging to recognise the importance of this work and the advantages to the manufacturer of having his own thoroughly efficient and well-organised system of inspection.

Before the war the speaker had been in practice for a number of years as an inspecting engineer, dealing with a great variety of plant and materials and in those days it was a rare thing to find even the most elementary form of works inspection or check gauging. Now things had changed and there was no doubt that in the future every works should have such a department, carefully suited in functions and scope to the class of work turned out.

In view of the large place inspection would take in the future, it is well that it should have a correct nomenclature and the speaker suggested that the practice of the Woolwich Inspection Department should be followed in distinguishing between inspectors and examiners. Roughly, the distinction might be made that the former worked mainly—though not entirely—with their heads and the latter mainly though by no means entirely with their hands. The title of inspector should be applied to those in a works inspection department who were in corresponding positions to the managers, their assistants and, in some cases, the foremen. Those who actually carried out the routine gauging were called examiners.

The Institution of Engineering Inspection, of which the speaker was a member, hoped to include in its membership as many as possible of those engaged in works inspection who, like the author of the paper, were qualified to organise and supervise this important branch of manufacturing activity. This Institution had recently been formed out of the Technical Inspection Association, which was an outcome of the Munitions Inspection Department, and it planned to encourage the employment of inspection by users, buyers and makers of the plant, machinery and materials used in engineering. Its motto boldly declared that inspection directly helped to increase and extend industrial operations and did not, as some manufacturers thought, hinder them.

Mr. V. W. Delves-Broughton said he would confine his remarks to two points, the first being that in practice, soft screw gauges were found to outlast the same in a hardened state. The reason for this appeared to be that the grit adhering to the screws under test adhered to the softer material and eroded the harder in the manner of a lap, whereas if soft gauges were used the grit became embedded in the surface of the gauge which it thus protected from further wear. The life of a soft gauge was found to be about 11,500 screws, whereas a hard gauge would not be in a fit state to use after 6,000 to 7,500, the longer life being during damp weather when less dust was flying about in the shops and view room. Of course a soft gauge was more liable to destruction by force being applied but no class of gauge will long survive such usage. The screw gauges were tested every day to see that they had not suffered during use. Another great point in favour of a soft gauge was the ease with which it could be produced. Where extreme accuracy was required hardened gauges became a necessity as it was not practicable to produce soft gauges with the same accuracy as hardened ones.

As an indication of how efficiently the gauging was carried out under his control, Mr. Delves Broughton would like to state that out of 7,000,000 2 B.A. screws which were gauged by his assistants, not a single complaint was received concerning the screw threads, but several cases of undercut heads were met with which he accepted full responsibility for passing.

In no single case did he succeed in breaking a bolt, passed by the viewers in his charge, when broken by shock applied through a nut screwed to the other end—the bolts always failed in the screw threads.

The speaker's second point was the question : Has any satisfactory practical workshop method been found for testing screw threads in blind holes ?

He had found that Paragon Case Hardening Steel was perhaps the most suitable material to employ in most cases where the gauge was made in one piece with no adjustable anvils, etc., when cast iron, as mentioned in the paper, was the most suitable material for the body or frame. He did not know where this material was to be obtained but if carbonised at a temperature between 825° and 850°, and quenched in oil from 850°, followed by a second quenching in water at 800°, it gave excellent results with very slight distortion in the process, provided that the carbonising had not been continued for too long a time and that the articles had been properly packed and supported whilst undergoing the carbonising process.

After rough grinding all gauges, etc., should be thoroughly " aged " by alternately heating to about 200° and cooling in ice mixed with salt, the transition from hot to cold not being hurried or the article was liable to fly.

Mr. Delves - Broughton fancied that the wonderful stabilising effect of this treatment was little known to engineers although well known to metallurgists.

A point mentioned in the discussion was the question of maintaining both the gauge and the article at the gauge at the same temperature if not at the standard temperature of 15° Cent. A simple method was to immerse both object and gauge in oil or soda water maintained at the required temperature.

Major W. Allsop, A.M.I.Mech.E., M.I.E.I., said the wear of gauges was an important point often overlooked and should, as pointed out by the author, be catered for when laying down tolerances as far as possible, *i.e.*, tolerances should be so arranged as to sign (+ve or—ve), as to give an increase of life to the gauge. It was wrong to have the limits and tolerances the same in inspection and workshop gauges. Those in a workshop gauge should be so arranged that whatever work passed the workshop gauges MUST be passed by the inspection gauges, whether manufacturer's and/or purchaser's inspection gauges. To ensure this the workshop gauges must *not* take advantage of the full tolerance allowed in the work in fixing the gauge limits, and gauge tolerances should be of opposite sizes as compared with inspection gauges. This gave a better chance of guarding against wear of the workshop gauges, which, as stated by the author, was greater on workshop gauges. Thus rejections at a later stage are avoided with all the extra expense, recrimination and what not.

The definition of Tolerance might advantageously conform to the B.E.S.A. definition now well known: "a difference in dimensions prescribed in order to tolerate unavoidable imperfections of workmanship." True, the example makes the author's meaning clear.

LIMIT. No., the actual dimension, *e.g.*,
High limit ... 1·002″
Low limit ... 1·000″
or in case quoted—
High ... ... 2·0005″
Low ... ... 1·9995″

It might not yet be generally known that the B.E.S.A. was now about to recommend to industry the Unilateral System of Holes with a hope that it would eventually be gradually adopted by all in place of the Bilateral hole used by many firms.

They were putting forward a standard series of shafts common to both the Unilateral and Bi-lateral systems. They hoped that this common system as regards the shaft would make conversion from the Bi-lateral to the Unilateral system easier for such as use the former. The latter appeared to be coming into universal use.

He hoped that some present would give their views on this question and also on the minor points raised by him, as there appeared to be a lax use of common, often-quoted "terms."

Mr. Ackermann, B.Sc.(Engineering), M.Cons.E., said that one of the marked omissions, probably covered by the author's introductory remarks, was inspection by aid of Rontgen rays. This method was particularly useful for assembled parts of aeroplanes, as it enabled the inspector to see whether the wooden struts were fully entered into their metal socket, and whether the fixing screws were sufficiently long. It also enabled blow holes to be detected, and could be used in many similar ways.

The improved standard of work turned out by various firms as a result of war work was most marked. During the war, he had had to inspect a number of factories of controlled owners for the purpose of advising what amount of the cost of their war plant they should be allowed to write off out of their excess profits, and in the case of a large firm of makers of textile machinery, they had told him how surprised they were at themselves for the accuracy of the work they had been able to do as the result of being put to it by war work. The "fit" in the case of cotton looms was usually about $\frac{1}{8}$ inch clearance, and even with this some of their customers had complained that the fit was too tight and could they make future machines with $\frac{1}{4}$ inch clearance! In spite of this, this and other similar firms, worked during the war to 1,000th part of an inch.

The fact that inspectors had not been allowed any discretion during the war reminded him of a particular case where he had his attention called (although it was not part of his work) to the fact that an aero engine cylinder, which had cost about £15, had been rejected by an inspector. The firm which showed it to the speaker challenged him to discover what the defect was, but he had to give it up, and was then shown a small tool mark on one of the radiation ribs, for it was an air-cooled engine cylinder. He remarked to the firm that the more such marks on the ribs, the better, as it would increase the radiating surface, in fact the surface would be better for sand blasting. They said that they fully realised that, and that was why they were so upset at having had the part rejected by an inspector.

The Author's Reply.

The author said in reply to Mr. Becks that he much appreciated his attention being called to the omission of any reference to the effect of temperature when gauging parts necessitating a high degree of accuracy. In such cases great care was taken that the work to be measured was handled as little as possible, and that it was at the same temperature as the atmosphere of the apartment where the measuring machine to be used was located, and where the measuring was carried out. In the case of gauges in constant use, a common method was to use some form of heat non-conducting material to encase the handle.

As regards Mr. Becks' question relative to the possibility of having the maximum diameter of a shaft as large or larger than the minimum diameter of the hole in which it must enter, the author was of opinion that this position could not arise if the fixing of limits and tolerances was carried out on similar lines to those indicated in the example he used to illustrate his definitions of the terms " Limit," " Tolerance " and " Clearance." If a 2 inch hole had a nominal dimension of 2 inches, then the shaft to enter it should not be shown as a 2-inch shaft.

The question raised by Mr. Gutteridge of inspecting screw threads by means of silhouetting them upon a screen was not used extensively by manufacturers of internal combustion engines and automobile engineers. It was more suitable and adaptable to the work of makers of tools, taps, etc., or measuring machines involving very accurate thread work.

In replying to Mr. Bath Spencer's remarks, the author agreed that his suggestion to differentiate between inspectors and examiners was a desirable one, but if the author might suggest it, he was inclined to favour the term viewer in preference to examiner as being less cumbersome.

The author expressed his surprise that Mr. Broughton intimated that a soft screw gauge had a longer life before it than a hard one inasmuch as, apart from the explanation given, the gauge would be very susceptible to damage by slight knocks or other accidents and thus would be only too readily put out of action.

The author was not aware of any special method of testing the accuracy of threads in blind holes, but thought that if the taps used were up to standard and the threads looked good and the screw plug gauge fitted, it was improbable that there was anything seriously wrong with the threads.

Although agreeing with the assertion of Major W. Allsop that shop gauges should not take full advantage of the tolerances allowable on the work, the author issued a word of warning, that in the enthusiasm of obtaining the best possible work, and the longest possible gauge life, the economic limit line might be overstepped in which case the desired results would be negatived by a corresponding increase in the costs of production.

The author had expected that there would have been more discussion than there had been on the question of the advantages of the unilateral as opposed to the bilateral system of stating limits on drawings. Although there appeared to be an attempt to force upon the engineering trade the former method, there were still many who had not yet experienced the alleged shortcomings of the latter method and were consequently unconvinced of the desirability of making any change in a system which had served them satisfactorily for years past.

In reply to Mr. Ackermann's remarks regarding the use of the X-rays in connection with the inspection of parts similar to those referred to in the paper, the author said that up to the present this had remained outside his sphere of operations.

As regards Mr. Ackermann's remarks on the tool-marked fin of an air-cooled cylinder, the author said he was well able to appreciate Mr. Ackermann's feelings, as he came up against many things of a similar nature when in charge of certain inspection work on the production of the A.B.C. Dragonfly aero engine. This engine was air-cooled, but the fins were sand-blasted and copper plated, so that in this case any slight tool marks were not discernible when the cylinder was finished. Many of the rank and file of the A.I.D. had but little idea as to the ultimate use of the parts they inspected, and consequently much delay would be occasioned by these people holding up components because a " lightening hole " was " half a thou." larger in diameter than the prescribed limits of ±·005" ! !

(*Taken as read on Monday, March 5, 1923.*)

MR. G. A. BECKS, A.M.I.C.E., VICE-PRESIDENT,
IN THE CHAIR.

THE PHYSICAL PROPERTIES OF CLAY

(*Fifth Paper*)

AND THE

DYNAMICS OF PILE-DRIVING

By A. S. E. ACKERMANN, B.Sc.(Engineering), A.C.G.I., M.Cons.E., A.M.I.C.E.

During the nine months that have elapsed since the presentation of the fourth paper, experiments Nos. (259 to 309) were made, but some of the results are not recorded herein, as the work is not yet sufficiently complete. Such time as has been available has been given to reading, thought and calculations, and the results are recorded herein.

Dynamics of Pile-driving.—As a result of the information obtained by means of the autographic pile-set gauge (Fig. 1), described at pp. 157–171 of the fourth paper, a much fuller and closer estimate of the various forces involved in pile-driving has been made possible. As an illustration, the case of the Simplex steel pile-tube, of which particulars are given at IV., p. 199, may be taken.

The potential energy of a pile-driving hammer is expended in several ways :—

(1) overcoming the friction of the " leaders " which guide the hammer.

(2) causing damage (" brooming") to the head of the pile.

(3) producing heat in the head of the pile.

(4) elastically compressing the pile.

(5) overcoming the inertia of the pile.

(6) overcoming the friction of the soil on the sides of the pile.

(7) overcoming the vertical reaction of the soil on the toe of the pile.

(8) elastically compressing the soil under the toe of the pile, and stretching the clay adhering to the sides of the pile.

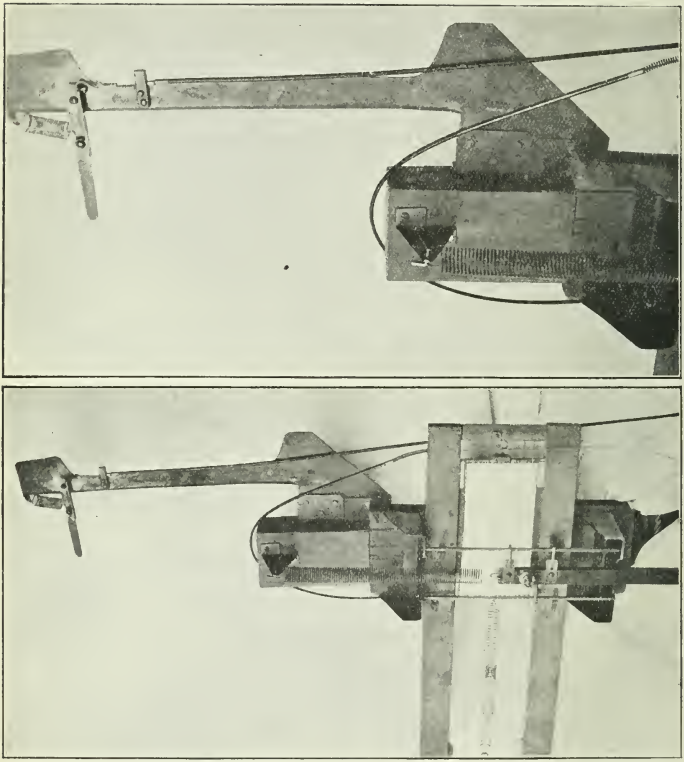
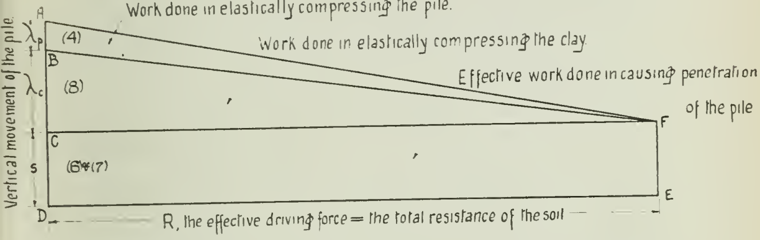


FIG. 1.

Of these Nos. (1) to (5) inclusive and No. (8) are losses, and only (6) and (7) are used in doing what is required, viz., driving the pile into the soil. The quantities (4), (6), (7) and (8) can be represented by a diagram. The force expended in overcoming the inertia of the pile (5), considerably reduces the effective force of the blow, but it is not entirely lost, as, having given a velocity to the mass of the pile, the pile itself then possesses kinetic energy which is at least partly utilised when the velocity of the pile is decelerated.


Work done in elastically compressing the pile.
Work done in elastically compressing the clay
Effective work done in causing penetration of the pile
A
B
C
D
E
F
λ_p
λ_c
s
(4)
(8)
(6)+(7)
Vertical movement of the pile
R, the effective driving force = the total resistance of the soil

NOTE:—BF is assumed equal to CF

FIG. 2.

λ is the total elastic compression of the pile *and* clay, and is recorded by the autographic pile-set gauge.

λ_p is the total elastic compression of the pile.

λ_c is the total elastic compression of the clay.

s is the set of the pile recorded by the gauge and produced by one blow of the hammer.

R is the resistance in tons to the motion of the pile due solely to the friction of the clay on its sides and the vertical reaction of the clay on the toe of the pile.

$$\lambda_c = \lambda - \lambda_p \quad \ldots\ldots\ldots\ldots \quad (1)$$

The mean force F expended in giving motion to the *pile itself, i.e.*, in overcoming its inertia, *apart from the side friction and reaction on the toe*, can be calculated if we know the duration of the blow of the hammer and the mass of the pile. The time-scale of the gauge has not yet been accurately calibrated, but it has been estimated (IV., pp. 163 and 165), and consequently the duration of any particular blow recorded by the gauge can also be estimated.

In the case of the Simplex steel pile-tube used in Exp. (285) —IV., p. 199—the following are the particulars :—

W = the weight of the hammer = $38\frac{1}{2}$ cwts. = 1·925 tons.

A = area of cross-section of steel tube = 47·12 sq. ins.

M = mass of pile-tube = 2·115 tons.

λ = 0·375 in. (recorded by the gauge).

s = 0·250 in. ,, ,, ,,

$\lambda + s$ = 0·625 in.

H = height from which the hammer is dropped on to the head of pile = 5 ft.

a = the mean acceleration of the motion of the pile due to the blow in f.s.s.

t = the duration of the blow in seconds.

p = the compressive stress in tons per sq. in. on the material of the pile due to the blow.

e = the elastic compression per unit length of the pile in inches.

E = the modulus of elasticity of the material of the pile in tons per sq. in.

l = the length of the pile in inches.

To obtain a first approximation (but greater than the true) R' of the value of the effective force R due to the blow, we see that the work done is that represented by the diagram Fig. 2 *plus* the work done in giving motion to the pile itself against its mean inertia F through the distance

$$(\tfrac{1}{2}\lambda_p + \lambda_c + s)^* \qquad \text{.......... (2)}$$

Thus the work done in overcoming the inertia of the pile *per se* is

$$F(\tfrac{1}{2}\lambda_p + \lambda_c + s) \qquad \text{.......... (3)}$$

where $F = Ma$

t is the time taken by the *head* of the pile to move the distance $(\lambda + s)$, and is given by the pile-set gauge.

In the case of Expt. (285) t appears to have been 0·0124 second. Hence

$$(\lambda + s) = \tfrac{1}{2}\,\mathrm{at}^2 \qquad \text{.......... (4)}$$

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* Only $\frac{1}{2}\lambda_p$ because F cannot come into action until the pile has been elastically compressed.

In a similar manner it may be pointed out that penetration of the soil cannot take place until the compressive force on the pile is at least equal to $(R + F)$, and that if the elasticity of the material of the pile is such that the pile cannot resist this force, then penetration will not take place, but the pile will be damaged.

$$\therefore \frac{0 \cdot 625 \text{ in.}}{12} = \frac{a}{2}(0 \cdot 0124)^2$$

$$\therefore a = \frac{2 \times 0 \cdot 625}{12(0 \cdot 0124)^2} = 677 \, f.s.s.$$

$$F = Ma = \frac{2 \cdot 115 \times 677}{32} = 44 \cdot 7 \text{ tons.}$$

F is the *mean* force required to overcome the inertia of the pile. It is zero at first contact of the hammer on the head of the pile; it increases to a maximum F_m, and then decreases (as the pile comes to rest again) to W, the weight of the hammer resting on the head of the pile. Hence

$$F = \frac{0 + 2F_m + W}{4} \quad \therefore F_m = 2F - \frac{W}{2}$$

F_m must be deducted from R', when it has been calculated as a first approximation to R.

Thus $R' - F_m = R''$ ....(5), a closer approximation of the effective force R due to the blow.

The gross kinetic energy of the hammer at the moment it first touches the head of the pile [disregarding the losses (1), (2) and (3)] is equal to its potential energy when ready to be dropped.

Thus the gross energy is

$WH = 1 \cdot 925 \times 5 \times 12 = 115 \cdot 5$ in.-tons ....(6)

Hence $R'\left(\frac{\lambda}{2} + s\right) = 115 \cdot 5$..(7)

$\therefore$ R' $(0 \cdot 1875 + 0 \cdot 250) = 115 \cdot 5$ $\therefore$ $R' = 264$ tons, and this is the force on the *head* of the pile due to the blow.

From (5) $R' - F_m = R''$

Substituting $(2F - \frac{W}{2})$ for F_m

we have

$R' - 2F + \frac{W}{2} = R''$ and putting in the values of the known symbols

$$264 - 89 \cdot 4 + \frac{1 \cdot 925}{2} = R''$$

$$\therefore R'' = 175 \cdot 6 \text{ tons.}$$

By means of R'' a good approximation to the value of λ_p can be calculated, for by Hooke's Law :—

$p = \frac{R''}{A} = eE = \frac{\lambda_p}{l}E$ ....(8)

E for mild steel is 13,500 tons per sq. in.

$$\therefore\ p = \frac{175 \cdot 6}{47} = \frac{\lambda_p}{360} 13{,}500$$

$$\therefore\ \lambda_p = \frac{360 \times 175 \cdot 6}{47 \times 13{,}500} = 0 \cdot 0988 \text{ ins.}$$

λ, recorded by the gauge, was $= 0 \cdot 375$ ins.

$$\therefore\ \lambda_c = \lambda - \lambda_p = 0 \cdot 375 - 0 \cdot 099 = 0 \cdot 276 \text{ in.}$$

The work-done due to the inertia of the pile is thus by (3)

$$F(\tfrac{1}{2}\lambda_p + \lambda_c + s) = 44 \cdot 7(0 \cdot 049 + 0 \cdot 276 + 0 \cdot 250)$$
$$= 44 \cdot 7 \times 0 \cdot 575 = 25 \cdot 7 \text{ in.-tons.}$$

Thus of the gross potential energy of the hammer of 115·5 in.-tons, 25·7 are expended in causing motion of the pile *per se*, thus leaving 89·8 in.-tons for doing the work represented by the diagram Fig. 2. Thus finally

$$R\left(\frac{\lambda}{2} + s\right) = 89 \cdot 8$$

$\therefore\ R = \dfrac{89 \cdot 8}{0 \cdot 438} = 205$ tons, this being the total resistance offered by the soil to the movement of the pile. Having thus calculated all the forces involved, a check can be made as follows :—

As R' is the maximum force on the *head* of the pile, and R is the total resistance offered by the soil, therefore $(R' - R)$ must be $= F_m$, the maximum force required to give motion to the pile on account of its inertia.

Substituting $(2F - \frac{W}{2})$ for F_m we have

$$R' - R = 2F - \frac{W}{2}$$

$$264 - 205 = 2F - 0 \cdot 96$$

$\therefore\ F = 30$ tons, whereas previously it was calculated to be 44·7 tons, thus indicating that the values of the other forces are only approximate ; but a variation in the value of F does not have a large percentage effect on the values of R and R', which are the principal forces it is required to know, and the foregoing value of R may be compared with that which is obtained by a common method of calculating it, namely,

$$W \times H = R \times s,$$

W, H, and s being the only quantities known when an autographic pile-set gauge is not used.

$$\text{Thus } 1 \cdot 925 \times 5 \times 12 = R \times 0 \cdot 25$$

$\therefore$ $R = 462$ tons, which the author has no hesitation in stating is hopelessly inaccurate. For example, this method, when applied to the case of some $14\frac{1}{2}$ in. × $14\frac{1}{2}$ in. × 30 ft. pitch-pine piles, with which the author recently had to deal in connection with a Chancery action, gave $R = 684$ tons per sq. ft., while the crushing strength of pitch-pine is about 340 tons per sq. ft., and as several hundred piles were driven without crushing them, we may be certain the value of R was far less than the value just calculated. As a rough indication that the author's method gives more likely results, reference may be made to the reports of the Whangpoo Conservancy Board (IV., pp. 172-3), where it will be found that the dead loads applied to the full-size piles to cause them to penetrate the soil nearly up to their heads were of the order of 200 tons.

The foregoing calculations may be summarised in the following manner :—

	In.-tons	%
*(5) Energy necessary to overcome the inertia of the pile	25·7	22·3
*(4) and (8) Energy lost in elastically compressing the pile and the soil	38·6	33·4
*(6) and (7) Energy available for overcoming the resistance R of the soil to penetration	51·2	44·3
Gross potential energy of the hammer ...	115·5	100·0

Looking at the diagram, Fig. 2, p. 27, it is seen that the force R is overcome through the distance s. Hence $Rs = 51 \cdot 2$ in.-tons

$$R = \frac{51 \cdot 2}{0 \cdot 25} = 204 \cdot 8 \text{ tons,}$$

which agrees with 205 tons previously calculated at p. 30.

Though the phrase "elastically compressing the clay" at the toe of the pile has been used, it should be stated that this is intended to cover the elastic stretching of the clay adhering to the sides of the pile. It is due to this elastic compression and stretching that the pile, on being left for some time, is slightly extruded from the clay. It is for this reason, too, that it is important that the driving should be as continuous as possible, so that there is little time for this elastic extrusion to take place, as if it does it means so much lost work. There is the additional reason that if much time is allowed between one set of blows and another, the clay is forced into more intimate contact with the sides of the pile by the surrounding clay.

Attention may also be drawn to the large forces involved in pile-driving, even when allowances have been made for the factors of time, inertia, and the elastic compressions; *e.g.*, in the case just dealt with the least force acting on the whole pile is about 200 tons, which is several times the working load that would be put on it. Hence also the pile itself, which may be of timber or ferro-concrete, is severely tested in the driving, especially when the set becomes small while a considerable length of the pile is above ground and, therefore, unsupported laterally by the soil. Consequently it does not seem necessary to make separate tests of piles *in situ*, for if they stand driving without showing signs of weakness or defect, then they will most probably safely stand any working load which it is usual to put on them. Of course, too, when the forces are known so much more accurately, a smaller factor of safety will suffice. Thus in the case taken, dividing the 264 tons $= R'$ (p. 29) by 10 gives practically the same result as dividing the 462 tons (p. 31) by 20; but it must not be assumed that these factors of safety would always bear the ratio of one to two. It is obviously best to get as near to the facts as possible, and then allow a factor of safety, which consequently may be smaller with even greater safety.

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* The references are to the corresponding quantities at p. 25.

CONNECTION BETWEEN THE BRINELL & MEYER HARDNESS NUMBERS FOR METALS AND THE PRESSURE OF FLUIDITY OF CLAY.

At p. 773 of *Nature*, of December 9, 1922, there is a most interesting letter, headed "A Curious Feature in the Hardness of Metals," by Mr. Hugh O'Neill and Dr. F. C. Thompson, in which they point out that "by combining Meyer's formula

$$L = ad^n*$$

"with that for the ordinary Brinell test

$$H = L \div \frac{\pi D}{2}\left(D - \sqrt{D^2 - d^2}\right)$$

"the following result is obtained:—

$$H = \frac{2}{\pi D}\, a^{\frac{2}{n}}\, L^{\left(1-\frac{2}{n}\right)}\left\{D + \sqrt{D^2 - \left(\frac{L}{a}\right)^{\frac{2}{n}}}\right\}$$

"In this the second term ceases to have a real meaning "when

$$D = \left(\frac{L}{a}\right)^{\frac{1}{n}}$$

---

* L = the load on the ball in kilos.
d = the diameter of the indentation in mm.
D = the diameter of the ball in mm.
a and n are constants, and H is the hardness number.

" Beyond the load corresponding to a value

$$L = aD^n$$

" the hardness becomes imaginary, or, in other words, *the load* " *will be sufficient to force the ball through the material continu-* " *ously* . . . ."

The author's delight on reading this can probably be realised only by those who have had a similar experience! He wrote on December 11th to the editor of *Nature* (the letter appears at p. 17 of the issue of January 6, 1923) pointing out that the phenomenon which had been so cleverly predicted by MM. O'Neill and Thompson had in fact been discovered by the author in the case of clay, and that anticipating a similar result in the case of metals, he had also obtained a like effect with lead. It is pointed out in that letter that the pressure of fluidity is numerically equal to *twice* the hardness number, and that the reason for this is that the Brinell number is obtained by dividing the load by the area of the *curved* surface of the indentation, whereas in the case of the pressure of fluidity the load is divided by the *projected* area, and that the area of the curved surface of a hemisphere is exactly twice the area of its flat surface. It is also shown that if Meyer's formula is true for clay, n must be $= 2$, and on this assumption the values of a for clay containing different quantities of water, in Meyer's formula are given.

Thus five men working in four independent " groups " have done work which beautifully dovetails together!

The author has recently (January 17, 1923) had the satisfaction of finding that this is not the only case of agreement between the results obtained by other workers by experiments on metals and those obtained by him with clay. He refers more particularly to a paper entitled " A Law Governing the Resistance to Penetration of Metals when Tested by Impact with a 10 mm. Steel Ball; and a New Hardness Scale in Energy Units," by Prof. C. A. Edwards, D.Sc., of the University of Manchester, and F. W. Willis, B.Sc. (Tech.), which appears at pp. 335-369 of the *Journal of the Institution of Mechanical Engineers*, June, 1918. At p. 349 thereof will be seen a number of excellent curves for different metals, the ordinates being impact-energy in inch-pounds, and the abscissæ, indent-diameter in mm. If these be compared with the author's curves for clay forming Sets I. and II. at p. 46 of his first paper, the similarity will be found to be striking. In the case of clay, square pyramids were slowly forced, point down, into clay, and the curves connect the loads in grams (ordinates) and the penetrations in mm. (abscissæ).

At p. 358 *ibid* the scale of hardness of various metals is given in " energy units." This may be compared with the author's results at pp. 196-200 of his second paper, where the work-done per c.c. of clay displaced by various penetrating bodies is recorded. At p. 367 (2) *ibid* MM. Edwards and Willis give the following law :—

"The results obtained indicate that there is a law governing the resistance to penetration of metals which are capable of plastic deformation. This law, which applies to the very soft metals and to hardened tool steel, may be expressed by the equation :

$$d = CE^{0\cdot 25}$$

where d equals the diameter of the indent made by a 10 mm. ball, C equals a constant which varies with the hardness of the metal, and E equals the total energy of impact."

It will, therefore, be highly interesting to see how this law, which is for the impact of a loaded sphere on metals, agrees with that given by the author for steady pressure on an inverted square pyramid penetrating into clay, at p. 45 of his first paper.

Take the case of the large pyramid and 30 % of water in the clay. The equation is :

$$h^2 = 11\cdot 6\,L \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (9)$$

$$\therefore L = \frac{h^2}{11\cdot 6}$$

where h is the penetration in cms. and L is the load on the pyramid in kilograms.

The work done in causing the pyramid to penetrate the clay is

$$E = \int L dh = \int \frac{h^2}{11\cdot 6} dh = \frac{1}{11\cdot 6}\,\frac{h^3}{3} = 0\cdot 0287\,h^3$$

$$\therefore\ h^3 = \frac{E}{0\cdot 0287} \quad \therefore\ h^2 = \frac{E^{\frac{2}{3}}}{(0\cdot 0287)^{\frac{2}{3}}} \quad \dots\dots\dots\dots (10)$$

If b be the length in cms. of a side of the square hole formed at the surface of the clay by the penetration of the square pyramid, and a be half the angle at the apex of the pyramid, then $b = 2h \tan a$

Tan a for the large pyramid = 0.340

$$h = \frac{b}{2 \tan a} \qquad h^2 = \frac{b^2}{4\,(0\cdot 340)^2} \quad \dots\dots\dots\dots\dots\dots\dots\dots (11)$$

Equating (10) and (11).

$$\frac{b^2}{4\,(0\cdot 340)^2} = \frac{E^{\frac{2}{3}}}{(0\cdot 0287)^{\frac{2}{3}}} \quad \therefore \frac{b}{2 \times 0\cdot 340} = \frac{E^{\frac{1}{3}}}{(0\cdot 0287)^{\frac{1}{3}}}$$

$$b = \frac{0\cdot 68}{0\cdot 306}\,E^{\frac{1}{3}} = 2\cdot 22\,E^{\frac{1}{3}}$$

or generally $b = c\,E^{\frac{1}{3}}$ for clay.......................................(12)

Hence the only material difference is that for clay, and a steady force, the index of the power of E is $\frac{1}{3}$ instead of $\frac{1}{4}$ as it has been shown to be for impact on metals by Prof. C. A. Edwards and Mr. F. W. Willis. They record that the index of the power of E varies from 0·24 to 0·27. If the 0·24 was for the hard steel and 0·27 was for tin, then the 0·33 for clay seems to indicate that the index increases slightly as the material tested is softer.

This agreement of the results obtained by independent workers on substances, which, though evidently similar in many respects, differ so widely as clay and hard steel, is most satisfactory, if not remarkable.

It was thought it would be interesting to obtain an expression for the work done per c.c. displaced—

(*a*) in the case of clay.

(*b*) in the case of metal (from Prof. C. A. Edwards' results).

It was found (I., p. 45) that in the case of the large square pyramid and 30% of water, the total volume of clay displaced was

$$V = 6{\cdot}08\,L^{\frac{3}{2}}\ c.c. \quad \text{..(13)}$$

E, the total work-done, has just been shown to be equal to $0{\cdot}0287\,h^3$, therefore the expression for the work-done in cm.-kilos. per c.c. for the large pyramid is

$$\frac{0{\cdot}0287\,h^3}{6{\cdot}08L^{\frac{3}{2}}} = {\cdot}00473\,\frac{h^3}{L^{\frac{3}{2}}} \quad \text{....................................... (14)}$$

From I., p. 45 $h^2 = 11{\cdot}6\,L$

$$\therefore\ h^3 = 11{\cdot}6^{\frac{3}{2}}L^{\frac{3}{2}} \quad \text{..............................(15)}$$

Inserting this in (14) we find that of work-done per c.c. is constant and equal to 0·186 cm.-kilo. per c.c.

From (11) $h = \dfrac{b}{2\,tan\,a} = \dfrac{b}{0{\cdot}68}$ and on substituting this for h in (14) we find the work-done per c.c. of clay displaced is equal to

$$0{\cdot}015\,\frac{b^3}{L^{\frac{3}{2}}} \quad \text{...(16)}$$

In the case of the Brinell tests, it is *d* which is measured, consequently for (*b*) above we need an expression in terms of *d* and *D* for the volume of the indentation, which is a segment of a sphere. This is found to be

$$V = \frac{\pi}{24}\left\{2D^3 - \sqrt{D^2 - d^2}\,(2D^2 + d^2)\right\} \quad\dots\dots\dots\dots\dots\dots(17)$$

Edwards' equation for the energy of the blow is

$$E = \left(\frac{d}{C}\right)^4 \quad\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(18)$$

∴ the work-done by impact per unit volume of displacement in the case of metals is

$$\frac{E}{V} = \frac{d^4}{C^4\frac{\pi}{24}\left\{2D^3 - \sqrt{D^2 - d^2}\,(2\,D^2 + d^2)\right\}} \quad\dots\dots\dots\dots\dots\dots(19)$$

and when the ball has penetrated the metal up to its max. diam then $d = D$, and (19) becomes

$$\frac{E}{V} = \frac{D^4}{\frac{\pi}{12}C^4\,D^3} = k'D \quad\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(20)$$

which implies that in the case of metals the work-done per c.c to cause displacement is *not* independent of the diam. of the ball causing the displacement of the metal, whereas in the case of clay it *is* independent as far as the experiments have gone. Equation (20) implies that for a given ball the work-done per c.c. displaced is constant, but at least in the case of mild steel (the only results which the author has examined), given at p. 351 of the paper by Edwards and Willis, this does not seem to be the case, as the following table (taken partly from the paper cited, and the deductions calculated by means of equation (19)) shows :—

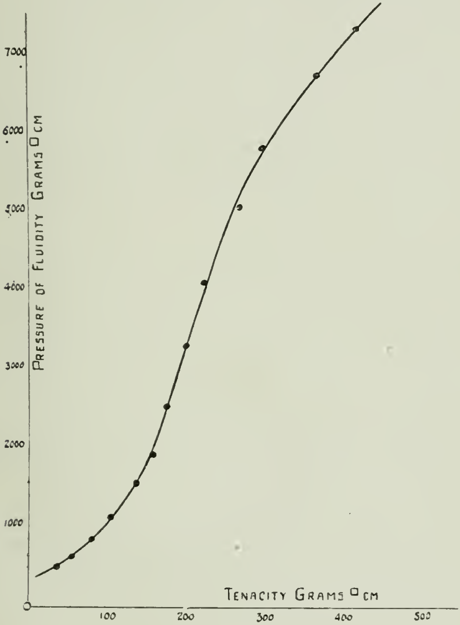
Weight in pounds.	Drop in inches.	Diameter of indentation in mm.	Work-done in in.-lb. per c. mm. displaced.
7	20	4·84	11·42 k
7	15	4·44	12·28 k
7	10	4·04	13·32 k
7	5	3·36	9·83 k

$$\text{where } k = \frac{1}{\frac{\pi}{24}C^4}$$

FURTHER AGREEMENT OF THE LAWS FOR METALS AND CLAY.

Chapter XVIII., p. 267-295, Vol 1 of *Mechanical Testing*, by Batson and Hyde (Chapman & Hall, 1922) is on Hardness and Abrasion Tests.

At p. 269 it is stated that Foeppl found that for metals the surface of indentation was proportional to the pressure applied. This is *Conclusion* No. 1 of p. 78 of the author's first paper.



PRESSURE OF FLUIDITY AND TENACITY OF CLAY

SET XXXV.

At p. 272 it is recorded that Meyer found that the mean pressure per unit area is constant for a given angle of indentation whatever the diameter of the ball. The law for clay (I., p. 55) is the same.

At p. 273 it is said in connection with the Brinell test that the time effect is most marked up to about 10 seconds' application of the load, but after that the effect is very small. In the case of clay the author found 10 minutes was the time necessary for the penetrating body to come practically to rest (I., p. 103, penultimate par.).

At p. 274 we learn that numerous named observers have shown there is a close relationship between the Brinell Hardness Number and the ultimate tensile strength of a material. The curve forming Set XXXV. at p. 37 hereof connects the values of the pressure of fluidity and the tensile strength of clay as recorded in the author's papers I. and II.

At p. 285 we find that Martel found the work of the falling ram was proportional to the volume of the indentation, and that he, like Prof. C. A. Edwards and Mr. F. W. Willis, expresses hardness as the work required to produce unit volume of indentation. This is *Conclusion* No. 25 of the author (II., p. 225).

At I., p. 83, Mr. P. M. Crosthwaite, in the discussion, said that on examining the author's results given in Tables I. to IV., he found $\frac{W + w}{b^2} = \text{constant}$.

In replying to the discussion on that paper the author did not refer to this, but he has since examined it. At I., p. 47, the author recorded that $\frac{W + w}{4\,A} = \text{constant}$ for a particular pyramid and percentage of water in the clay. Hence, if it is also true that $\frac{W + w}{b^2} = \text{constant}$, it means that $b^2 \propto 4\,A$. At I., p. 39, it is shown that $b^2 = 4\,A_V \tan a$ and that $A_V = A \cos a$

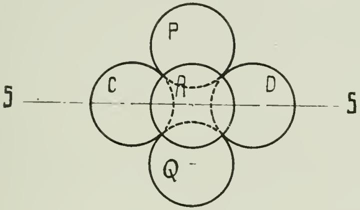
$\therefore$ $b^2 = 4A \cos a \tan a$, *i.e.*, b^2 *does* $\propto 4A$, and, therefore, Mr. Crosthwaite's statement is another way of putting what the author had recorded, *viz.*, that $\frac{W + w}{4A} = \text{constant}$.

Even in the case of wind, Dr. T. E. Stanton's experiments show that when the wind is steady there is no variation in the pressure per sq. ft. due to a variation in the size of the surface exposed to the wind. This corresponds with the results and statement recorded at p. 55, I.

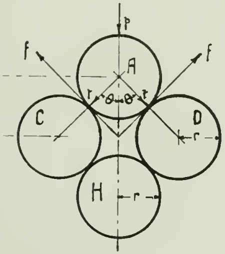
Hypothesis to account for the Phenomenon of the Pressure of Fluidity of Substances, and its connection with their Tenacity and Molecular Friction (or Shearing Strength).

Assumptions: (1) That the particles of the substance are spheres; (2) that there is cohesion, and friction between the spheres at their points of contact ; (3) that the weights of the spheres are negligible.

With regard to (1) it may be pointed out that other workers on clay have made this assumption ; *e.g.*, in estimating the total surface of the particles in one gram of clay as 4,220 sq. cms.; and Prof. Sven Odén has proposed that " the ' effective radius ' of a particle should be defined as the radius of an imaginary sphere of the same material which would sink in water with the same velocity as the particle in question."



I. PLAN



II. VERTICAL SECTION ON S—S

FIG. 3.

The clay is supposed to be loaded by a disc. The spheres are considered to be in horizontal layers of which a portion of three layers is shown in II. of Fig. 3.

The portion of the total vertical load W on the disc taken by *one* sphere is p, thus $np = W$ where n is the number of spheres in each horizontal layer.

In the vertical section θ is the angle in the vertical plane between the vertical line and line of centres AC. t is the thrust, due to p, down the lines of centres AC and AD.

Consider O, the centre of the square $ACHD$ (Fig. 3, II.), formed by the 4 centres of the 4 spheres, then because $OA = OC$ $\therefore \theta = 45°$.

The vertical force p produces four equal thrusts t, each inclined at an $\angle\theta$ to p.

The top sphere A is trying to squeeze in between the 4 spheres $CQDP$ (Fig. 3).

If f be the total friction at each of the four points of contact between the sphere A and the 4 supporting it, then each f acts on A upwards and outwards at an $\angle$ $(90-\theta)$ to the vertical, tending to *prevent* A from squeezing between its 4 supporting spheres.

Thus p is equilibrated by

(*a*) the 4 vertical components of the 4 t's.

(*b*) ,, ,, ,, ,, 4 f's.

The vertical component of t is $t \cos\theta$

,, ,, ,, f ,, $f \sin\theta$

$\therefore \quad p = 4t\cos\theta + 4f\sin\theta$ ....(1)

If μ be the coefficient of friction at the points of contact of the spheres, then $f = \mu t$..(2)

The author's experiments have shown that μ is NOT constant for clay, but *decreases* with the pressure between the surfaces of contact, and for clay containing 25% of water it has been found that the relationship is $\mu = \frac{9 \cdot 47}{\sqrt{p_n}}$ where p_n is the normal pressure between the surfaces. It is true the surfaces were *wood* against clay, but as the clay adhered to the wood, the result is correct for the clay on clay, *i.e.*, shear.

Hence (2) must be written (*when* w', the % of water, is 25%)

$$f = \frac{9 \cdot 47}{\sqrt{t}}\, t = 9 \cdot 47 \sqrt{t} \quad \text{...(3)}$$

And *probably* we may write $f = k\sqrt{t}$ ....(3a) where k is a constant for any particular value of w'.

The values of k corresponding with different values of w' must be determined by separate experiments.

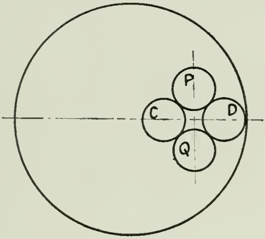
Subs. (3) in (1).

Then $p = 4t\cos\theta + 4k\sqrt{t}\sin\theta$ ....(4)

So far we have considered the equilibrium of only the sphere A. Now consider the four spheres $PCQD$ (Fig. 3).

There is a sphere H below these (and vertically under A), the forces between H and the 4 being identical with those between A and the same 4.

Thus there *two* spheres A and H trying to squeeze in between the four $PCQD$, and the horizontal, radial, outward resultant force acting on each of the 4 spheres $PCQD$ is $2\,t\,\sin\theta$. This, in the case of all the spheres vertically under the disc, is equilibrated by adjoining groups of 6 such as the one we are considering, but in the case of the *peripheral* spheres the net radial outward force is what displaces the spheres in the adjoining clay, beyond the cylinder of clay under compression, which adjoining clay is subject only to the ' head ' of clay above it. (This pressure head was in one experiment only 1/17 of the pressure head under the disc.) Let us call the horizontal *resistance* (on one peripheral sphere) of the adjoining unartificially loaded clay h.



PLAN of DISC

FIG. 4.

Another force resisting the radially outward movement of the peripheral sphere D is due to the horizontal component of the friction f of each of the spheres A and H on the sphere D say, D being considered now as a peripheral sphere.

This horizontal resisting force is, therefore, $2f\cos\theta$. There is finally another force resisting outward movement of the peripheral sphere, viz., that due to the cohesion of D to the spheres P and Q respectively at their points of contact.

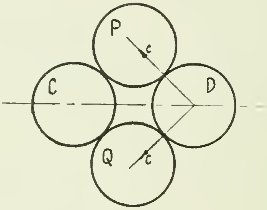
From Fig. 5, it is seen that the combined effect of these two cohesions is $2\,c\cos 45°$. Hence the net radial, outward, horizontal force H on D is

$$2\,t\,sin\theta - \overset{\textit{friction}}{2\,f\,cos\theta} - \overset{\textit{cohesion}}{2\,c\,cos\,45^\circ} - \overset{\substack{\textit{resistance}\\ \textit{of adj. clay}}}{h}$$

In the initial, or *pre-fluidity*, stage θ has been shown to be $= 45^\circ$.

$$\therefore\quad H = \sqrt{2}\,t - \sqrt{2}\,f - \sqrt{2}\,c - h = \sqrt{2}\,(t - f - c) - h \ldots\ldots(5)$$

When H is negative no flow takes place, *i.e.*, the phenomenon of Pressure of Fluidity does not take place. When $H = O$ there is unstable equilibrium, and when H is just positive the Pressure of Fluidity has been reached and flow takes place, and the comparative suddenness with which the phenomenon starts is due to the breaking away of the sphere D from two of the four in contact with it, viz., P and Q, when the cohesive force c at their points of contact can no longer resist the ruptive force, *i.e.*, when the ultimate tensile strength of the material has been reached.



III PLAN

FIG. 5.

Subs. (3a) in (5).

$$\text{Then } H = \sqrt{2}\,(t - k\,\sqrt{t} - c) - h \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

A similar argument applies to the adjoining clay, *i.e.*, that which is *not* vertically below the disc and which is, therefore, not subject to any artificial load W, but only to its own weight.

Let the resulting vertical force on one sphere be p', and t' and f' be the forces corresponding with t and f.

c, the cohesive force, will be the same as before, and the relation $f' = \mu t' = k\,\sqrt{t'}$ will still hold, where k depends on w' as before.

In order to get an expression for the value of h (last line, par. 3 of p. 41) we have only to imagine the system of spheres shown in Figs. 3 and 4, turned through a right ∠, so that p is horizontal instead of vertical, and then call this horizontal passive *resistance* h (NOT active pressure, which we know is O, because the unloaded clay does NOT crush into the hole above the disc). Then the same reasoning will establish a similar set of equations.

$$\text{Thus } h = 4t' \cos\theta + 4f' \sin\theta$$
$$= 4t' \cos\theta + 4k\sqrt{t'} \sin\theta \quad \text{.........................(4a)}$$

Now when a sphere, say A', is forced radially and horizontally inward (corresponding to A downward) into the unloaded clay, it separates 4 spheres (corresponding to $PCQD$) radially in a *vertical* plane, and one of these (say D') may be considered as moving vertically upwards against the *head* of the clay on it. Suppose, for simplicity, we consider an *un*loaded column of clay of diameter equal to that of the disc and immediately adjoining the loaded column, then if p' be load on A', $np' = W'$, the weight or head of the unloaded column of clay.

Now the upward vertical thrust V of D' corresponds with H of equa. (5), and we have

$$V = \sqrt{2}\, t' - \sqrt{2}\, f' - \sqrt{2}\, c - p' \quad \text{...............................(5a)}$$

p′ replacing h

$$\therefore\ V = \sqrt{2}\, t' - \sqrt{2}\, k \sqrt{t'} - \sqrt{2}\, c - p'$$
$$= \sqrt{2}\, (t' - k\sqrt{t'} - c) - p' \quad \text{.............................(6a)}$$

When V is negative no flow takes place; when $V = O$ there is unstable equilibrium, and when V is just positive we have the phenomenon of Pressure of Fluidity.

In any case p' is known because it is = the density of the clay multiplied by the head. c must be determined by a tensile test of the clay—*for all this reasoning is to establish a relation between pressure of fluidity and tenacity*, the relation of friction or shear and pressure having already been established by experiment—then by (6a) when $V = O$ we can obtain t'.

Substituting this value of t' in (4a) and θ being 45° we are able to find h. Substituting this value of h in (6) when $H = O$ we obtain the value of t, and finally substituting this value of t in (4) *we obtain p the pressure of fluidity.*

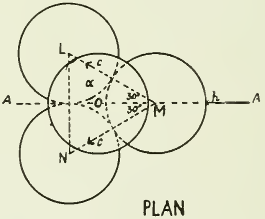
Conversely, of course, if we determine p we obtain t from equa. (4), substituting this in (6) when $H = O$ we obtain h, substituting this in (4a) we obtain t', and substituting this in (6a) when $V = O$ we obtain p', which means we have found what the maximum static head of clay must have been while we determined p by experiment.

Actually, as far as the author's experiments have gone, p seems almost independent of p′. Lordly, in America, has repeated some of the author's experiments on a larger scale, carrying the penetration to three times the depth. For all this apparently p was unaffected by p'; in other words, when once the phenomenon has started (which it usually does when the penetration is about equal to twice the diameter of disc) it goes on until the disc nearly reaches the bottom of the vessel containing the clay. This being so, it would appear that we may ignore h in equation (6), and thus when $H = O$

$$c = t - k\sqrt{t} \text{ nearly} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6b)}$$

$$\text{or } t - k\sqrt{t} - c = O \qquad \therefore \quad \frac{+k \pm \sqrt{k^2 + 4c}}{2} = \sqrt{t}$$

and thus t is known, and inserting the value for t in (4) we obtain the value of p, the pressure of fluidity, which is a great simplification.



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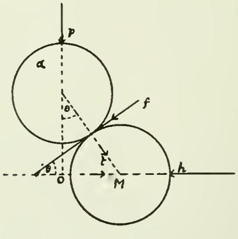


VERTICAL SECTION ON AA

Fig. 6.

So far we have considered only the square pyramid form of stacking the spheres. A closer and, therefore, more likely arrangement is the tetrahedral.

Using the same symbols as before, and considering the equilibrium of the top sphere a (Fig. 6).

$$\begin{aligned} p &= 3\,t\cos\theta + 3\,f\sin\theta \\ &= 3\,t\cos\theta + 3\,\mu t\sin\theta \\ &= 3\,t\cos\theta + 3\,k\sqrt{t}\sin\theta \quad \ldots\ldots\ldots\ldots(7) \end{aligned}$$

Considering the equilibrium of *one* of the three supporting spheres L, M and N, the horizontal outward thrust due to t of the top sphere (which, of course, acts down the line of centres) is $t\sin\theta$, and due to a fifth sphere a' below L, M, N, and vertically under a there is an equal thrust $t\sin\theta$ on *each* of the three bottom spheres. The total horizontal thrust on each of L, M, N is therefore $2\,t\sin\theta$, which is equilibrated by equal and opposite horizontal thrusts in the case of the 'internal' groups (as before); but in the case of the peripheral groups there is the less horizontal force h (as before). Also the horizontal component of each t (of which there are 6) will be resisted by the resultant of the cohesions of the three bottom spheres L, M, N, taken two at a time.

Thus in Fig. 6, OM is the direction of the hor. comp. of the two t's, which acts at M and the two cohesions resisting this act in the directions ML, and MN, the angle LMO being 30°. Lastly, the outward horizontal motion of, say M, will be resisted by the horizontal comp. of the friction between M and a and M and a' $= 2\,f\cos\theta$.

Thus when flow occurs

$$\begin{aligned} 2\,t\sin\theta &= 2\,c\cos 30^\circ + 2\,f\cos\theta + h \\ &= \sqrt{3}\,c + 2\,k\sqrt{t}\cos\theta + h \quad \ldots\ldots\ldots\ldots(8) \end{aligned}$$

In order to obtain an expression for h, we may again imagine the group of spheres turned through an $\angle$ 90°, so that the line of thrust of p becomes horizontal, and we call this hor. thrust h.

$$\begin{aligned} \text{Then } h &= 3\,t'\cos\theta + 3\,f'\sin\theta \\ &= 3\,t'\cos\theta + 3\,k\sqrt{t'}\sin\theta \quad \ldots\ldots\ldots\ldots(7a) \end{aligned}$$

$$\text{and } 2\,t'\sin\theta = 2\,c\cos 30^\circ + 2\,k\sqrt{t'}\cos\theta + p' \quad \ldots\ldots\ldots(8a)$$

The pressure head p' in the unloaded clay being the head multiplied by the density as before (*i.e.*, in case of square pyramid) we obtain t' from (8a), and inserting its value in (7a) we obtain h. Inserting this in (8) t is determined, and putting this in (7) p is found. Or, also as before, we may start by determining p experimentally, and then by the reverse operation find p', or knowing p' we may find c.

But as h has been found to have little if any effect on the value of p, we may write

$$2\,t\,sin\,\theta = 2\,c\,cos\,30^\circ + 2\,k\,\sqrt{t}\,cos\,\theta \text{ nearly} \quad \ldots\ldots\ldots\ldots(8b)$$

and k and θ being constant, t is seen to depend directly on c only, and knowing one the other is thus determined.

Inserting the value of t in (7) p is easily found.

From (8b) we see that flow will not take place until $2\,t\,sin\,\theta =$ or slightly $>$ $(2c\,cos\,30^\circ + 2\,k\sqrt{t}\,cos\,\theta)$.

Hence it is seen that if for any plastic material the values of any two of the three properties tenacity, shear and pressure of fluidity are known, then the value of the third may be calculated.

Experimental Test of the Hypothesis.

When w' (the water content of the clay) is 25%, $\mu = \frac{9 \cdot 47}{\sqrt{t}}$, where t is the pressure between the surfaces.

$$\therefore \quad f = 9 \cdot 47\sqrt{t}, \qquad i.e.\ k = 9 \cdot 47.$$

The tensile strength c of clay containing 25% of water has been found experimentally to be 180 grs. per sq. cm. Inserting this value of c in (8b) we have :—

$$2\,t\,0 \cdot 577 = 2 \times 180 \times \frac{\sqrt{3}}{2} + 2 \times 9 \cdot 47\ \sqrt{t} \times 0 \cdot 817$$

$$\therefore \quad 1 \cdot 154\,t = 15 \cdot 46\sqrt{t} + 312 \quad \therefore \quad t - 13 \cdot 4\sqrt{t} - 270 = 0.$$

$$\therefore \sqrt{t} = \frac{13 \cdot 4 \pm \sqrt{(13 \cdot 4)^2 + 1080}}{2} = \frac{13 \cdot 4 \pm 35 \cdot 47}{2} = 24 \cdot 44$$

$\therefore$ $t = 595$. Inserting this value of t in (7) we have :—

$$p = 3 \times 595 \times 0 \cdot 817 + 3 \times 9 \cdot 47 \times 24 \cdot 44 \times 0 \cdot 577$$

$$= 1{,}457 + 400 = 1{,}857 \text{ grs. per sq. cm.}$$

The value of p determined experimentally is 1,960 grs. sq. cm. Thus the calculated value is only $5\frac{1}{4}$% less than the true value.

Second Test of the Hypothesis by means of Data obtained by Experiments with Clay.

At p. 97 of Paper III. values of μ for $w' = 29 \cdot 5\%$ are given, and from the curve of tenacity and w' we find $c = 50$ grs. □ cm. when $w' = 29 \cdot 5\%$. On plotting p_n and μ (taking the *mean* of the three results for $p_n = 41$ grs. □ cm. as *one* point) we find k in $\mu = \frac{k}{\sqrt{p_n}}$ is *not* constant but varies between $6 \cdot 85$ for $p_n = 30$, to $6 \cdot 46$ for $p_n = 47 \cdot 5$. *Ex*terpolating for $p_n = 193$,

k is *probably* $= 6\cdot0$ or less, and using *this* value in equations (8b) and (7) we have :—

(8b) $1\cdot154\,t = 86\cdot6 + 2 \times 6\sqrt{t} \times 0\cdot817$

$\therefore\ t - 8\cdot48\sqrt{t} - 75 = 0$

$$\therefore\ \sqrt{t} = \frac{8\cdot48 \pm \sqrt{(8\cdot48)^2 + 300}}{2} = \frac{8\cdot48 \pm 19\cdot3}{2} = 13\cdot89$$

$\therefore\ t = 193$ grs. □ cm.

(7) Hence $p = 3 \times 193 \times 0\cdot817 + 3 \times 6 \times 13\cdot89 \times 0\cdot577$
$= 473 + 144 = 617$ grs. □ cm.

while the experimental result was 560 (read from curve). Hence the equations in this case give p 10% too *much.*

Obviously for checking the formulæ it is necessary to know the values of $p, f,$ and c for a particular material. Unfortunately, the author is not possessed of this information except for two conditions of the clay just used. Hence the following rough tests are the best that can be made at present as regards metals.

ROUGH TEST OF THE HYPOTHESIS BY MEANS OF THE VALUES OF p, f, AND c FOR MILD STEEL.

f, the shearing strength of mild steel, is about 16 tons per sq. in.
= 2,470 kilos. per sq. cm.

c, the tensile strength of mild steel, is about 29 tons per sq. in.
= 4,590 kilos. per sq. cm.

Inserting these values in equations (8b) and (7) we have

(8b) $1\cdot154t = 4{,}590\sqrt{3} + 2 \times 2{,}470 \times 0\cdot817$
$= 7{,}935 + 4{,}030 = 11{,}965$

$$t = \frac{11{,}965}{1\cdot154} = 10{,}360 \text{ kilograms per sq. cm.}$$

(7) $p = 3 \times 10{,}360 \times 0\cdot817 + 3 \times 2470 \times 0\cdot577$
$= 25{,}400 + 4{,}274 = 29{,}674$ kilos. per sq. cm.

Cf. O'Neill and Thompson's predicted value of 18,340 kilos. per sq. cm. for a particular steel, for which the above values of f and c may not be correct.

A specimen of mild steel, ¾ in. diam. and 1·5 in. high, crushed by the author, gave an ultimate resistance of 50 tons per sq. in. allowing for the increase of diam. due to the crushing. 50 tons per sq. in. = 7,870 kilos. per sq. cm. This is much less than either of the values given above, but it must be remembered the conditions are very different. The 29,674 value refers to the penetration of a hard steel ball or disc 10 mm. in diam. into a lump of steel, while the 7,870 value refers to the crushing of a small column of mild steel. The corresponding stresses for cast lead-tin alloy given in IV., p. 152, are, pressure of fluidity 1,233 kilos per sq. cm., and the ordinary compressive stress 245·5 kilos. per sq. cm. (mean of the two). Thus in that case the effect of the lateral support, due to the surrounding metal was to raise the resistance to compression $\frac{1{,}233}{245 \cdot 5} = 5 \cdot 03$ fold.

If the values taken for mild steel are reliable, the corresponding increase is $\frac{29{,}674}{7{,}870} = 3 \cdot 78$ fold. In the case of clay containing 25·5% of water the pressure of fluidity was 2·0 kilos. per sq. cm., but such clay, when unsupported laterally by other clay (IV., p. 198) offered a resistance to compression of only 0·205 kilos. per sq. cm., so that the increase due to lateral support in that case of clay was 10 fold.

TEST BY MEANS OF THE VALUES OF *p*, *f*, AND *c* FOR CAST LEAD-TIN ALLOY.

The author has now had the time to determine the values of *f* and *c* for the *same sample of lead-tin alloy* as he used to determine *p* in Exp. (260) IV., p. 152. These values are :—

$$f = 156 \text{ kilos. per sq. cm.}$$
$$c = 244 \quad ,, \quad ,,$$

Then from (8b) $1 \cdot 154\, t = 244\sqrt{3} + 2 \times 156 \times 0 \cdot 817$

$= 422 + 255 = 677 \therefore t = 587$

(7) $\therefore\ p = 3 \times 587 \times 0 \cdot 817 + 3 \times 156 \times 0 \cdot 577.$

$= 1436 + 270.$

$= 1706$ kilos. per sq. cm., which compares roughly with the experimental result of 1,233 kilos. per sq. cm., being 27·7% too high.

Mr. R. H. H. Stanger, of the Broadway Testing Works, Westminster, kindly made a shearing test of piece of cast lead, 2 ins. square, in the presence of the author. The max. load was 3·50 tons. The stress was, therefore, 0·875 ton per sq. in. = 138 kilos. per sq. cm.

The value of *c* obtained from Trantwine's "Engineers' Pocket Book," was 145 kilos sq. cm. These low values of *f* and *c* led to inquiry about the "lead" and it was found that an unknown quantity of tin was alloyed with it.

FURTHER TESTS OF THE HYPOTHESIS BY MEANS OF THE VALUES OF *f*, *c*, AND *p*, FOR DIFFERENT METALS, each SET OF VALUES BEING OBTAINED FROM THE SAME PIECE OF METAL.*

The author has much pleasure in acknowledging his indebtedness to Mr. R. H. H. Stanger, A.C.G.I., A.M.I.C.E., for generously making the necessary 21 tests to determine the values of *f*, *c*, and *p* for the seven metals given below. He is also indebted to the various firms named below for kindly presenting him with the necessary pieces of metal and preparing the specimens free of cost ready for the respective tensile, shearing, and pressure of fluidity tests.

For the aluminium specimens : The British Aluminium Co., Ltd. For the mild steel specimens : David Colville & Sons, Ltd. For the lead, tin and zinc specimens : Dewrance & Co. For the copper specimens : Elliott's Metal Co. For the Muntz metal specimens : The Muntz's Metal Co., Ltd.

It is not the mere monetary value of such assistance which the author wishes to acknowledge, but the sympathetic encouragement and appreciation of the work which such practical assistance carries with it.

The shearing tests were made with bars 25 mm. square and 200 mm. long.

The tensile tests were made with test pieces having screwed ends (1 in. Whitworth), the plain cylindrical portions being 15mm. diam. and 150mm. long.

The specimens for the pressure of fluidity tests were 70 mm. diam. and 70 mm. high.

The steel punch, which in effect was equivalent to a disc, was similar to that used for the first test of lead and described at p. 151 of IV., but instead of being only 7·5 mm. diam. was 10 mm. diam and the length of the shank (9 mm. diam.) 56 mm. The diam. of 10 mm. was chosen so as to correspond with Brinell's 10 mm. ball, which Edwards and Willis also used. This punch bent slightly on the aluminium and consequently a new one had to be made which was shorter and harder.

The following are the particulars of the metals :—

Messrs. Dewrance & Co., wrote, "The lead, tin, and zinc were all cast in sand moulds, with no further heat treatment. We have no chemical analysis, but bought them guaranteed to the following degrees of purity,—

Lead	99·9%
Zinc	99·9%
Tin	99·85%."

---

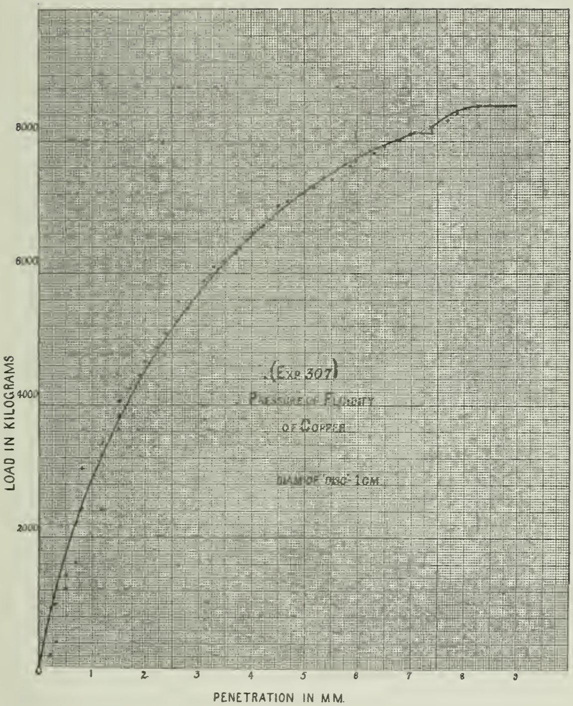
* The results of these tests for only lead and tin were ready in time to put on the blackboard at the meeting. Hence the absence of any remarks on them by the speakers

Metal.	Sp. gr.	Tensile stress at the Yield Point c′	Ultimate tensile strength c	Shearing strength f	Pressure of Fluidity by Expt. p	p_1 the calculated value of p using *f* & *c*	$\frac{p_1-p}{p_1}\times 100$ = % error	Elongation % on (*a*) 50.8mm. (*b*) 127·mm.	Contraction of area %	$\frac{f+c}{p}$
Lead—Tin alloy	—	—	244·	156·	1,233·	1 706·	+ 27·7	—	—	0·324
Lead	11·38	57·3	114·5	124·9	777·	1,072·	+ 27·5	(*a*) 72· (*b*) 59·	100·	0·308
Tin	7·30	102·3	223·	231·9	1,367·	2,025·	+ 32·5	(*a*) 76· (*b*) 50·5	86·	0·332
*Zinc	7·14	214·	214·	755·3	7,760·	4,707·	[— 64·8]	Nil.	Nil.	[0·125]
Aluminium ...	2·71	263·5	827·	577·3	4,015·	6,045·	+ 33·6	(*a*) 49·5 (*b*) 36·	60·	0·349
Copper	8·92	1015·	2192·	1445·	10,860·	15,590	+ 30·1	(*a*) 54·5 (*b*) 46·	65·	0·335
Soft Muntz's Metal	8·36	989·1	3686·	2004·	—	23,966	—	(*a*) 49· (*b*) 45·	45·3	—
Mild Steel ...	7·80	2499·6	4380·	2990·	—	31,625	—	(*a*) 40· (*b*) 29·3	55·5	—
						Mean	30·3		Mean	0·330

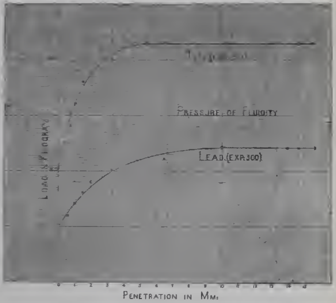
All stresses in Kilograms per square centimeter.

NOTE.—1000 kilos per sq. cm.= 6·35 tons per sq. in.

* In the case of Zinc the shear was not a true shear, nor was the pressure of fluidity normal. (*Vide p.* 51.)


(Exp 307)
Pressure of Fluidity
of Copper
Diam of Disc 1 cm
LOAD IN KILOGRAMS
8000
6000
4000
2000
0
1
2
3
4
5
6
7
8
9
PENETRATION IN MM.

Set XXXVIII.



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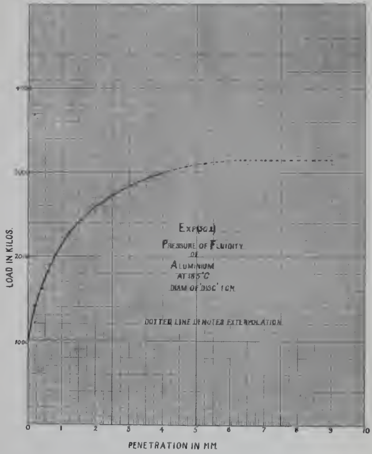
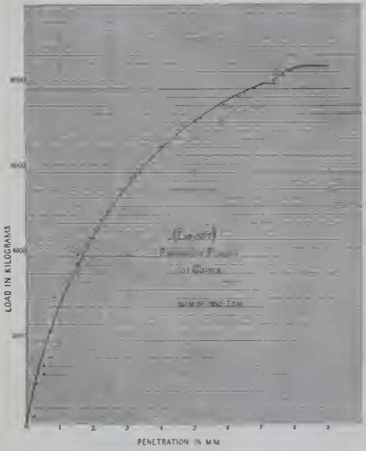


Set XXXVII.



Set XXXVIII

Messrs. Muntz's Metal Co., Ltd., wrote, " The Muntz's metal samples were cast in a chilled mould about 6 ins. diameter and then hot rolled to 3 ins. diameter, no further treatment was given.

" We regret we have not a complete analysis of the samples ; the composition is approximately 60% copper and 40% zinc with small quantities of lead and iron as impurities ; probably the total quantity of impurities would be under 5%."

Messrs. Elliots' Metal Company, Ltd., wrote in regard to the copper specimens, " The materials were cast in a 6 in. diameter billet and rolled hot to 3 in. diameter ; the samples were then turned from this.

" The shearing and tension test pieces were cut from the sides of the billet and not from the centre. The copper was made generally in accordance with the British Standard Specification No. 11 for copper stay rods, and assays—

Copper	99·4%
Arsenic	0·251%
Bismuth	Nil.

" Unfortunately, owing to an accident in turning, we were unable to make the tension specimen 15 mm. diameter and have turned it down to 12 mm. which we imagine will be equally suitable for the purposes required."

The British Aluminium Co., Ltd., wrote, " All the aluminium test pieces were cut and prepared from a 3 in. thick plate cast in a chill mould. Purity, 99⅓%."

The table of results at p. 50 of certain tests of seven metals needs little explanation. The experiments were made—

(*a*) To test the hypothesis submitted in explanation of the phenomenon of the pressure of fluidity.

(*b*) To determine whether the metals in question exhibited the phenomenon of a pressure of fluidity. The accompanying curves Sets XXXVI., XXXVII., & XXXVIII. completely establish this fact.

It was not expected that a metal composed of so many large crystals as zinc would conform to the " law." To realise fully how completely lacking zinc is in plasticity it is necessary to see the tested specimens. In tension this metal broke without any elongation or contraction of area. In the shear test, it did *not* shear, but broke by tension on two planes one on each side of the shear plane and about 10 mm. from it. In the pressure of fluidity test the specimen burst slowly at several places (in vertical planes), thus again failing by tension.

Rejecting the results for zinc as far as the hypothesis is concerned, the rest of the six metals of which the pressure of fluidity was determined experimentally, give results which, when used in the equations derived by means of the hypothesis, give values for the pressure of fluidity which, though they do not directly agree with the experimental values, are fairly consistently in excess of those values by an average of 30·3%. The maximum departure from this mean is only 3·3 = 10·9%. This may seem a good deal, but it has to be remembered that the hypothesis is based on the experimental determination of the tensile and shearing strengths of the metals which themselves vary. How much two tension tests of the same metal would have differed the author is unable to state, but two shearing tests were made of each metal and in the case of tin these differed by 4·3% on the smaller value; zinc 6·7%; and aluminium 5·5%. Hence the above 10·9% does not appear to be unreasonable.

If instead of using the ultimate tensile strength, the stress at the yield point is used, the results are much nearer to the experimental values of the pressure of fluidity, but they are more irregular. This is probably due to the fact that the metals tested (except mild steel) have no well marked yield point. Its value depends on the observer, and is therefore indefinite.

In their simplest forms, equations (8*b*) and (7) by means of which the pressure of fluidity can be calculated from the values of f and c are:—

$$(8b) \quad t = 1{\cdot}50c + 1{\cdot}42f$$

$$(7) \quad p = 2{\cdot}45t + 1{\cdot}73f$$

and combining these we have:—

$$(7b) \quad p = 3{\cdot}68c + 5{\cdot}21f.$$

An even simpler relation between these three quantities than that given by the hypothesis has suggested itself as a result of studying the hypothesis, viz., that $\frac{f+c}{p}$ is approximately constant for these metals.

The following are the values of this ratio:

Lead-tin alloy	0·324	Mean 0·330
Lead	0·308	
Tin	0·332	
Aluminium	0·349	
Copper	0·335	

In the case of the only two sets of results at present available for clay the ratio = 0·220.

It is regretted that the pressure of fluidity in the case of Muntz's metal and mild steel could not be determined because it was so great that a punch could not be made strong enough for the purpose.

The calculated value of the pressure of fluidity of mild is 31,625 kilos. per sq. cm. Deducting the 30% mean excess gives 22,137 kilos. per sq. cm. as the probable actual value, which is in fair agreement with O'Neill's predicted value of 18,340 kilos. per sq. cm.

As explained in paper IV., when the pressure of fluidity has been reached, the viscosity of the metal may be determined by observing the rate of penetration of the punch. In this manner the following values of the viscosity were determined :—

Lead	$2{\cdot}04 \times 10^{10}$	dyne seconds per sq. cm.
Lead-tin alloy* ...	$7{\cdot}37 \times 10^{10}$	,, ,, ,,
Tin	$16{\cdot}2 \times 10^{10}$	,, ,, ,,
Copper	$738{\cdot}0 \times 10^{10}$	,, ,, ,,

For further illustrations of the agreement of the results obtained with clay and metals, readers are referred to the "Hardness" papers by Mr. R. G. C. Batson, and Prof. W. C. Unwin, and the discussions of these and that of Prof. C. A. Edwards and Mr. Willis, all of which appear in the *Proc. Inst. Mech. Engrs.* for Oct. 18 and 25, and Nov. 15, 1918. Dr. Paul Ludwik's and Martel's results at p. 486-7 in particular might be noted. At p. 556, Mr. J. J. Guest showed that $\frac{\text{Load}}{d^2}$ must be constant for any metal. That is true also for clay. He also showed that $\frac{E}{d^3}$ "was necessarily constant for the material." This also is recorded for clay in the first paper.

The author wishes again to thank the Committee of the Dixon Fund of the University of London. The second grant which they made to him is still unexhausted and he hopes to continue the research. He must also thank the Government Dept. of Scientific and Industrial Research for the stimulation which is due to them. After the author's first paper was published he sent that department a copy and asked for a grant to cover out of pocket expenses of the work. This was refused, which had the effect of causing the author to be more determined to demonstrate by results that the work was worth encouragement ! On making a similar request to the University of London, a grant was at once made and the result is the last four of the five papers.

Lastly, the author gratefully acknowledges his indebtedness to his old friend Mr. Phil Lane, M.A. (Senior Optime, Cambridge Math. Trip.) for kindly checking the hypothesis *re* the pressure of fluidity. He reports that he has not found any 'snag' in it, but that, in order to offer adequate criticism, he would have to give two or three months of his spare time to the work. This was impossible as the author had only recently sent the MS. to him.

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* Given as lead in IV.

Mr. Hugh O'Neill, M.Sc., of the Victoria University of Manchester, wrote saying :—

" The results contained in Mr. Ackermann's paper are of great interest to me since they touch upon some work which I have lately undertaken and which will be published at the forthcoming meeting of the Iron and Steel Institute. Reference has been made to a letter to *Nature* (December 9, 1922), dated November 15th, entitled ' A Curious Feature in the Hardness of Metals.' The observations made there have interested Mr. Ackermann, and perhaps mention may be made of two further points.

" In the course of my work indentations with different loads on a 10 mm. ball have been made on pitch and plasticine. The time of loading was 2 minutes, and under these conditions Meyer's formula $L = ad^n$ holds. As Mr. Ackermann predicted, the value of n is $2{\cdot}0$ in each case, whilst a is $1{\cdot}83$ for pitch and $0{\cdot}015$ for plasticine.

" Tests on lead have also been carried out, and the pressure of perforation for a 10 mm. ball is found to be 579 kgs. This is equivalent to a pressure of 738 kgs. per sq. cm.—a value much lower than the 1,233* kgs. per sq. cm. reported at page 48 by Mr. Ackermann."

The Chairman then called on Mr. A. Honeysett to open the discussion.

Discussion.

Mr. A. Honeysett, A.M.I.C.E., said that he had carefully read the paper with an eye to the discovery of " snags," and he thought he had found one, although it was possibly only a misunderstanding which the author could explain. He referred to item No. 5 at p. 25, the loss of energy in overcoming the inertia of the pile ; this, as the author stated at p. 27, was not entirely lost, but he proceeded to reason as if it were entirely lost, and deducted 22·3 per cent. of the total energy in consequence ; but the speaker was unable to see that any of it could be lost as it existed as kinetic energy in the pile, and this could not be annihilated, but must be transmuted into something else as the pile decelerated. Since the resistance of the earth was the only counter force producing the deceleration, the only manner in which this energy could expend itself must be in increased penetration, hence it did not seem correct to reject this item which, it appeared to the speaker, should be included in the energy doing useful work. If it does not do this, perhaps the author might explain what becomes of it.

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* The " lead " which gave this result turns out to be an alloy of lead and tin, *vide* p. 48. Lead, as recorded in the table, p. 50, gave 777.

With regard to items (4) and (8) these were undoubtable losses, the energy being dissipated in hysteresis of the pile and the earth, and the author has quite rightly determined by an ingenious and elaborate calculation their relative amounts, but it appeared to the speaker that the conclusions arrived at were only correct at the commencement of the driving operation while the whole length of the pile was in the air, and all the earth resistance was concentrated at the point of penetration. This condition was only of academic interest and the real object of the investigation was to discover the conditions prevailing when the pile was driven fully home, so as to determine the real value of the factor of safety. It seemed to the speaker that as the pile entered the earth the resistance ceased to be concentrated upon the point and became distributed along the length of the pile, and in the case of a very long pile the resistance at the point might be practically negligible. In this case the pressure producing elastic deformation would not be uniform throughout the length of the pile, but would be reduced to nothing at the bottom, and the amount to be deducted from the total penetration would be one-half of that assumed by the author. If the assumptions of the speaker were justified, the energy producing penetration would be 95·8 inch-tons instead of 51·2, and the effective pressure and factor of safety would be proportionately increased. This was of course an error on the right side, as it made for safety, but if the investigations of the author were to be carried into the higher regions of physical research it appeared as if the points mentioned should not be ignored.

There was a considerable discrepancy in the two calculations by which F, the force to overcome inertia, was obtained, but this was probably due to an error in the measurement of the time occupied by the blow. It must be an exceedingly difficult matter to measure so short a period of time, and if instead of being 1/80 of a second as given, the time was really 1/100, this discrepancy would disappear. It was therefore evident that if the author's contention that the force F was wasted was correct, then an accurate determination of this time interval was of the utmost importance.

Another point to which the speaker called attention arose from the statement made at p. 31 that the elastic extrusion of the pile due to the reaction of the clay into which it was driven took a perceptible time. This must materially affect the percentage of loss due to the elastic reactions, as if the blows succeeded each other with such rapidity as to give only an insignificant interval compared to the reaction time of the clay, then only the first blow would suffer any loss from this cause, the second one not having to produce any elastic deformation, as it would occur with this deformation already in existence. It would be interesting to know whether the measurements quoted include this slow recovery or not.

The second portion of the paper, although allied to the first, dealt with an entirely separate branch of the subject, and was of absorbing interest as connecting, by similarity of physical phenomena, two such apparently unlike substances as clay and steel, and as tending to disclose one of those underlying and fundamental relationships the discovery of which was the real function of scientific investigation. The only point on which the speaker found himself in conflict with the author was in the ignoring by the latter of the components h and p'. This appeared to be done because within the limits of the experiments the magnitude of these forces was negligible, but it must not be forgotten that to leave them out of account altogether was to assume that the medium experimented upon was behaving as a perfect fluid, and this is inconsistent with the fact that the sides of the hole made by the disc did not fall in.

It could not matter to the clay whether the load upon it was produced by one material or another, and we could easily conceive of a disc being forced in so far that the intensity of pressure due to the height of the clay surrounding the hole became equal to that of the applied load inside the hole. In this case a condition of equilibrium was to be expected, and some further explanation would be required if, when such a condition were reached, the plunger still continued to sink.

The calculations are based entirely upon the existence of certain hypothetical spheres which, when held in a liquid medium, produced what was known as clay. This might or might not be true, but it seemed as if the hypothesis gave results well supported by the results of experiment, and we need not be ashamed of saying that we did not really know what clay was ; but we ought to be very cautious in transferring our knowledge of clay and its behaviour to solid substances, such as the metals, for we do know that the ultimate metallic particle was not a sphere but a crystal, and one would expect the mathematics of the subject to be altogether different.

The investigations appeared to give considerable probability to the view, already suggested by the known phenomena of sharpening and polishing of metals, that the crystals are really floating in a non-crystalline medium, and that this medium acts under pressure as if it were a liquid, which brought us to the final question, did we know what the difference between a solid and a liquid really was ?

Mr. Phil Lane, M.A. (Math.Trip., Cantab.), congratulated Mr. Ackermann on the research he had carried out in connection with the physical properties of clay, and regretted that he had only lately come into contact with this work. Mr. Ackermann had kindly asked him to look through his hypothesis to account for the pressure of fluidity, and this had greatly interested him. Whilst agreeing with Mr. Ackermann that, for the purpose of the hypothesis, it was probable that the small particles of the material considered might be taken to be spherical, he was not so sure that it was fair to assume that they were normally piled. If a number of spheres of any material were to be thrown into a receptacle, they would not arrange themselves in the uniform manner assumed in the hypothesis. The result of this would be that the calculated value of the pressure at which the material would display the phenomenon of the pressure of fluidity would be less than that calculated on the assumption of normal pyramidal piling. This fact appeared to be borne out by Mr. Ackermann's most recent experiments on metals in which the calculated value of the pressure of fluidity was in each case about 30 per cent. higher than that found by experiment. He suggested that an assumed form of piling in which the spheres were less closely packed than in the tetrahedral form used by Mr. Ackermann in his calculations would probably yield results more nearly in accordance with those obtained experimentally. In this connection he thought it would be interesting if the calculations were carried out for the form taken earlier in the paper in which each sphere of one layer was assumed to be resting on and in contact with four spheres of the layer below. He thought that this might lead to a closer approximation to the experimental results than the assumption taken in which each sphere of one layer was in contact with only three spheres of the layer below.

In connection with the hypothesis in general, he pointed out that the object was to co-relate certain experimental facts, and that the results so far obtained most certainly justified the general trend of the assumptions made. He felt that, pending any further experimental results which the hypothesis might fail to co-ordinate, the theory propounded by Mr. Ackermann should be accepted as a working basis for the mathematical investigation of the phenomena concerned.

Mr. P. J. H. Unna, A.M.I.C.E., said that just before Mr. Ackermann read his third paper on clay he showed him his pile-set gauge under working conditions. Mr. Ackermann, at that time, had merely designed the instrument with a view to measure the penetration of piles when there was no solid ground from which the levels could be taken by direct means. Such occasions are naturally few, being confined to instances in which isolated marine or river piles are driven from a barge. The further use to which Mr. Ackermann had now put his instrument led the speaker to hope that Mr. Ackermann might eventually be able to collect sufficient information to enable its use to give data which would indicate the safe load which piles would support, and that he might be able to lay down a few simple instructions by means of which such load could be determined from the diagram.

Sanders' rule for the safe loads on piles was probably the one which had been used most extensively, largely, no doubt, on account of its extreme simplicity. At all events, it had now been used for many years, and had not been found wanting. It was interesting to note that it was identical (except for the factor of safety of 8) with the formula $W \times H = R \times s$, which Mr. Ackermann quoted in his paper, and which he stated gave extremely incorrect results. This formula was intended to indicate the extreme force R of the blow, and he attempted to show that the value of R obtained therefrom would be about twice as large as it ought to be. Mr. Sanders presumably arrived at much the same conclusion, as he divided R by 8, and thereby allowed the reasonable figure of 4 as the factor of safety.

Another method, whereby the safe load for piles might be arrived at, was by drawing one or two up a few inches by means of jacks, and noting the force required to do so. Such force will be equal to the friction between the pile and the clay, plus the weight of the pile, and the effect of a partial vacuum. When a pile had been driven through soft ground, and when the shoe was still in such ground, and had not reached some hard stratum upon which it could rest, the friction had to be largely relied upon as taking the load. The force required for drawing the pile should give a good idea of the ultimate load which the pile would support, and it could be obtained more cheaply and more conveniently than by applying a test load. Thus, in the case of a whole timber pile, say, 25 ft. long, the weight would be about half a ton and the effect of suction about 1 ton. The actual frictional force would be the drawing force less $1\frac{1}{2}$ tons. The ultimate load would be friction plus support to shoe minus weight of pile. The double weight plus suction was 2 tons, and in softish mud might be taken as balancing the support obtained by the shoe, and the drawing force multiplied by a suitable factor of safety might be taken as the safe load. Take an actual case of three piles driven and tested under the conditions stated :—

Three 12 ins. × 12 ins. piles, about 26 ft. long, had final penetrations of 1 in. due to a 22 cwt. hammer dropped 6 ft. By Sanders' rule the safe load would be $\frac{22 \times 72}{8 \times 1} = 198$ cwts., say, 10 tons. The respective forces necessary to start movement of the heads of the piles when they were drawn some weeks after they were driven, were 15·3, 11·5 and 19·1 tons. These forces reached their maximum amounts when the heads of the piles had risen $\frac{1}{2}$ in., at which stage the compression in which the timber had been held by friction appeared to have been entirely relieved. These maximum forces were 38·3, 30·6, and 30·6 respectively, giving a mean value of 33·2 tons. In these instances, therefore, Sanders' rule gave factors of safety varying from 3 to nearly 4, the mean value being $3\frac{1}{3}$.

Mr. H. W. FitzSimons, B.Sc.(Engineering), A.M.Inst.C.E., referred to the pile-set gauge designed by the author and complimented him upon its efficacy. He called attention to the statement at p. 27 that the energy used to overcome the inertia of the pile was lost. Such energy could not be lost and probably confusion on this matter had occurred from the fact that the force produced to accelerate the pile was considerably in excess of the force of retardation, owing to the retardation period being of longer duration than that of acceleration ; but this force of retardation was necessarily part of the force pushing the pile into the ground.

If, from the autographic diagrams, sufficient information could be obtained to establish a satisfactory pile-driving formula considerable advantage would have been obtained. It was interesting to note that the old formula $R = WL \div 8s$ (Sanders) assumed the whole blow to be effective in driving the pile into the ground, but, it also assumed a factor of safety of 8, probably because it was very doubtful if the whole blow was actually effective. The author arrived at a figure of 44 per cent. as the effective part of the " punch " which if increased by an allowance for the above mentioned retardation force would probably amount to approximately 50 per cent., and this may be regarded as a round figure fact as at present ascertained from the pile-set gauge. Being a fact it would be consistent with practice to use a factor of safety more in the region of 4 than of 8, using 4 the result was obtained which was given by the simple formula stated above.

Pile-driving formulæ were very varied both as to form and results and might be regarded as thoroughly unreliable. Attention might be called to papers in the *Transactions* of the American Society of Civil Engineers, particularly one by Mr. E. P. Goodrich who dealt very thoroughly with the mathematical side of pile formulæ, based on the impact of a blow. Other writers dealt with pile formulæ on static principles. This raised the important question whether the supporting power of a pile should be estimated from forces occurring during driving or by forces acting between the pile and the ground after it had been driven and had come to rest. In this connection treatment up to the present had been based on theories of earth pressure similar to those used for ascertaining the stability of retaining walls.

Engineers were therefore liable to fall between two stools, for it was generally felt that no great reliance could be placed on results obtained from dynamic formulæ, and the one other topic which contained large elements of doubt as to its practical utility were the theories of earth pressure. The author may render assistance in the matter of selecting the correct pile formula. In passing it might be noted that engineers used piles to support loads statically; a moving pile supporting a load was not a desirable condition; it would therefore seem to suggest that static, rather than dynamic, formulæ could be developed with advantage.

Reference had been made in the discussion to the drawing of piles, and a case quoted in which the force to draw the pile was initially less than the subsequently required force. This should not be regarded as the general condition, for it was surely more usual to find the reverse to be the case; and often a driven pile that had to be withdrawn might be obstinate at the start but if given a few blows with the driving hammer could then be withdrawn by a smaller force.

Mr. A. Hiley, A.M.I.C.E., M.I.N.A., said he was much interested in the further experimental data given by the author, and observed more prominence had been given on this occasion to the "Dynamics of pile driving," proceeding out of the information obtained by means of the autographic pile-set gauge which was described in detail in his fourth paper.

When driving a considerable number of test piles at the British Steel Piling Company's works during the past year and using a steel tube 32 ft. 6 ins. long by 16 ins. diam. and $\frac{3}{4}$ in. thick for the purpose of depositing vibro-concrete piles *in situ,* he took measurements of the temporary compression set and of the permanent sets obtained by driving through hard substances with a 2 ton hammer. The records of 0.30 in. for λ and 0.25 in. for s, corresponded closely with the figures given by the author for precisely similar conditions.

In analysing the forces which acted on the pile-tube in the case of his own experiments, almost the whole of the temporary set could be accounted for by the elastic compressive strain occasioned in the material of the tube itself, whilst that increment which might have been due to the quaking of the ground was relatively small.

Referring to Fig. 2, the ordinate CF represented resistance of the ground which at first opposed the movement of the pile shoe, and the ordinate DE showed the resistance at the finish of the penetration through a distance CD for one blow. The area CFED represented the useful work done by one blow of the hammer, and as the final resistance might be a little more than that at the commencement of the permanent set when a hard stratum was reached, the mean resistance overcome, and which he had had in mind in the previous discussion when alluding to this at p. 180 IV., was the average value of CF and DE. If the tube were pressed down by an hydraulic ram no doubt the load-strain diagram would be triangular as shown by A F C, but as the pile was put into motion by a falling weight, the forces of impact entirely alter the character of the upper portion of the diagram.

The fact that the pile tube was fitted with a heavy doubling at its head and carried a massive cast steel helmet which contained a hardwood buffer or cap, brought into play considerable inertia forces due to the 2 ton hammer striking on these masses with a velocity of 18 ft. per second due to a free fall of 5 ft. That the inertia forces were great might be realized from the fact that, at impact, the hammer travelled 0·2 in. in 1/1000th of a second, and diagrams of the set which he had taken showed that a distinct vertical oscillation accompanied the compression strain of the pile tube, and further indicated that the force initially impressed on the pile cap was in excess of the resistance C F.

If the force opposing the motion of the hammer was uniform in amount throughout the travel $\lambda + s$ of 0·625 in., it would be equal to $\frac{115 \text{ inch-tons}}{0 \cdot 625} = 184$ tons, and for this condition the duration of the movement of the hammer retarded by the force of 184 tons would be $= \frac{\text{velocity}}{\text{deceleration}} = \frac{18}{184} \times \frac{1 \cdot 925}{g}$ $= \cdot 006$ second.

He thought it would have been better for his purpose, if instead of accepting the figure ·0124 of a second, which was of doubtful value and covered not only the acceleration period but the retardation period as well, the author had dealt with the calculation by taking into account the change of momentum occasioned by impact of two partially elastic bodies. By this method the questionable time element could be eliminated and in its stead an experimentally determined co-efficient of restitution for the materials of pile and hammer could be used to arrive at the kinetic energy possessed by the combination as soon as the blow had taken effect. When the kinetic energy had been thus calculated, a portion of it required to be deducted as lost in stressing the pile-cap, and the remainder could be considered to be expended in the elastic compression of the pile and in overcoming the ground resistance through the distance s. It was in this connection that an accurate measurement of $\lambda + s$ was essential for the purpose of estimating the resistance of the ground to penetration by the pile. The problem closely resembles that of the recoil of a gun subjected to a constant liquid-brake resistance in which the maximum velocity was reached after about 10 per cent. of the travel and from this point decreased in a parabolic curve to the finish of the recoil. Proceeding from this analogy he did not see that the use of formula (4), nor the estimate of the force F by its aid, gave a correct treatment to the case, because the acceleration period must finish and the pile commence to decelerate after a very small fraction of the travel and the means of knowing the actual velocity and where it was a maximum were lacking.

If one or two refinements covering minor losses were left out of account, it could be proved that after impact the kinetic energy available for doing work was equal to $\frac{W + Me^2}{W + M}$ times the striking energy of the hammer.

When W h was the striking energy expressed in inch-tons and W = weight of hammer; M = weight of pile and helmet; e = coefficient of restitution = 0·25 for iron striking on wood; e = 0·4 for iron on concrete; $e = 0 \cdot 5$ for iron on iron; $e = 0$ for iron on clay, then the

$$\text{K.E. of hammer plus pile after impact} = Wh \times \frac{W + Me^2}{W + M}$$

$$= 115 \times \frac{1 \cdot 925 + 2 \cdot 115 \times 0 \cdot 25^2}{1 \cdot 925 + 2 \cdot 115}$$

$$= 58 \text{ inch-tons.}$$

$$= 50 \text{ per cent. of the initial energy.}$$

$$\text{Energy expended} = R \times \left(\frac{\lambda}{2} + s\right)$$

$$\therefore R = \frac{Wh}{\frac{\lambda}{2} + s} \times \frac{W + Me^2}{W + M}$$

$$= \frac{58 \text{ inch-tons}}{\frac{0 \cdot 375''}{2} + 0 \cdot 25''}$$

= 130 tons resistance overcome in penetrating the ground.

This value of R was, he believed, too high owing to some minor losses which had not been detailed, but it was, even so, a good deal less than the 204 tons given by the calculation at p. 30. It followed that the percentages of losses shown in table at p. 31 should read 50 per cent., 22 per cent., and 28 per cent. respectively.

As so much energy was lost due to impact he was surprised to see it somewhat neglected in the calculations, and would venture to suggest that much more importance could well be attached to that aspect of the case, and much less to the overrated elasticity of the clay. If this view was shared, he thought the course would be clear to pursue further research into the dynamics of pile driving, and from carefully calibrated measurements of the set and compression of various types of piles to add considerably to the store of useful knowledge on this question.

Mr. Geo. A. Becks, Assoc.M.Inst.C.E., F.S.E., Vice-President, said he frankly confessed that he knew next to nothing regarding the subject under discussion, his idea being that one continued to drive piles until they ceased to go in any further, or until the top end commenced to broom when the pile top was cut off to the correct level and there the matter, or rather the pile, ended. Now, however, he knew better. It was necessary to continue the driving until the resistance of the pile equalled $R - R_1$, or words to that effect, and unless this were done something or other was sure to go wrong!

Mr. Ackermann had devoted an enormous amount of time and taken an infinity of trouble in obtaining results which could not fail to be of service, and for which he deserved an immense amount of thanks, as his contributions to the Proceedings of the Society were most valuable and tended to raise the status of the Society.

Mr. Becks expressd his unwillingness to believe that it was fair to compare steel with clay in so far as the Pressure of Fluidity was concerned. Clay, he thought would squeeze sideways upon the application of pressure, but judging from punchings taken from a punching machine it would be observed that they were invariably thinner than the plate from which they were punched. This, he contended, proved that the metal was compressed under the action of the punch, and the holes which were made in the samples lying on the table would, he felt sure, if the samples were cut open and the surfaces polished and etched, disclose that the grain of the metal had merely been compressed under the flat end of the punch. He might be wrong, he probably was, but that was how the matter appeared to him. Nevertheless he was not unwilling to be convinced, as he realised that hardness was only relative, but as one inexperienced in investigations of the nature Mr. Ackermann had been engaged upon, the results given were somewhat difficult to assimilate all at once.

Mr. Burnard Geen, M.Inst.C.E., Past President, wrote :—The proportion of useful work to the total work done in pile driving has long been the subject of discussion and difference of opinion. So much is this the case that many formulæ for determining safe loads on piles have ignored it altogether, and take no account of the weight of the pile. It cannot be conceived that people able to put forward such formulæ have been ignorant of the existence of the driving losses, and one can only assume that they have given up the question for lack of knowledge how to deal with them. The author's notes in this respect are of great value and a careful study of them will amply repay anyone engaged in using piles, if for no other reason than that it will reduce the range of error in calculation. The question of the safe bearing load of piles is one which cannot be entirely covered by any formula, or by the use of any apparatus ; as the exact nature of the soil through which the piles are being driven is never precisely known. This latter consideration may be sufficient to explain variations in results from many formulæ which are really " rule of thumb " formulæ concocted from data applying only to one set of conditions of subsoil at one particular spot on the earth's surface. The use of the author's Autographic Pile-set Gauge, which gives a written record of the set in a most convenient form, is one to be encouraged if prolonged trial shews that it will remain in good order under the vibration set up ; as it disposes of all reasonable doubt as to the actual net set, even when driving over water or through soil which is highly elastic. Given the accurate net set and following the author's suggestions it should be possible to obtain results closely in accordance with actual results in the field, if sufficient knowledge of the nature of the subsoil is available beforehand. If the forces produced in the pile by driving can be more accurately determined, it should be possible to obtain economy in the design of reinforced concrete piles ; as it is for these forces and for those occurring during slinging and pitching that the piles have to be designed ; and not for the static loads to be supported.

Dr. John W. Evans, D.Sc.(Lond.), F.R.S., F.G.S., wrote :—I have read your Memoir on the Dynamics of Pile-driving with the greatest of interest and instruction. It is an excellent piece of work. You have shown that the pressure of fluidity in the case of clay is strictly analogous to the lowering of the melting point when metals and other solid bodies are subjected to directed pressure. In each case the pressure concerned is an excess of pressure in one direction. In other words directed pressure or stress. General or hydrostatic pressure tends as a rule to *increase* the viscosity, and I should imagine that in the case of most substancss the greater the *general* pressure the higher would be *directed* pressure required to produce fluidity.

The Author's Reply to the Discussion.

The Author said that if any justification for his investigations into the dynamics of pile-driving were needed, it was contained in Prof. Henry Adams's paper on *Pile-driving and the Supporting Power of Piles*, read before the Concrete Institute on December 21, 1916. Prof. Adams had taken the data applying to a particular pile, and had calculated the ultimate and safe loads for it by means of 39 different formulæ and had given 39 different results in his paper. These "ultimate loads" varied from 37 tons (Hurtzig) to 333 tons (Rankine) and the "safe loads" varied from 5 tons (Rivington) to 67 tons (Rankine). In the author's opinion so great a variation practically condemned them all, and even to take the mean result was scarcely satisfactory.

In referring to Prof. C. A. Edwards's law $d = \mathrm{C\,E}^{n}$ (p. 34), the author stated that the value of C varied from 2·186 for tin to 0·748 for Shore's Hard Steel, and that he had since learned from Prof. Edwards that the variation in the value of n was from 0·24 for hard steel to 0·27 for tin, the author's value for clay containing 30% of water being 0·33.

At the top of p. 35, the author had given the relation $b = c\,\mathrm{E}^{\frac{1}{3}}$ where b was the length of the side of the square indentation made by the pyramid, instead of d the diameter of the circular indentation made by the ball. As it had been shown in paper I. that $\frac{\mathrm{L}}{b^2}$ was constant, it was justifiable to calculate d the diameter of the circle of equal area to the square of side b, and this being done gave $d = \mathrm{C\,E}^{\frac{1}{3}}$ where C, d, and E had the same meaning as in Prof. Edwards' equation. Then for clay containing 30% of water $d = 2{\cdot}51\ \mathrm{E}^{\frac{1}{3}}$

Similarly, as $\frac{L}{b^2} = \text{const.} \therefore \frac{4L}{\pi d^2} = c_1 \therefore L = \frac{\pi}{4} c_1\, d^2 = a\, d^2$ which is Mayer's equation, this relationship holding for the penetration of clay by an inverted square pyramid.

Mr. Becks had expressed the opinion that the metal did not flow from under the punch, but was compressed under it. The author agreed it might be slightly compressed, but this effect could only be slight, for if all the penetration of the punch were due to compression of the metal, then the latter would surely get much harder and therefore require a much larger load to cause subsequent penetration, but that was contrary to fact. The phenomenon of the pressure of fluidity was the curious fact that when the critical load on the punch had been reached the punch continued to sink into the metal without any additional load. Also, the specimens were bulged as a result of the experiment, showing the metal had moved laterally, and no increase of specific gravity had been detected.

Mr. Honeysett had taken exception to the allowance made for the inertia of the pile. The simplest way to consider this was by means of an example. Suppose two piles be identical in all respects except their weights, and let these be $\frac{1}{5}$ ton and 2 tons respectively. Let the weight of the hammer and its drop be 1 ton and 4 ft. respectively in each case, and the lengths of piles in the ground be the same, so that the total resistance of the soil was also the same. Then let the hammers drop. Was there any engineer who would contend that the heavier pile, weighing 10 times as much as the lighter one, would have as large a set as the lighter one? Obviously, if the heavier one were made very much heavier it would scarcely move at all. Hence inertia played an important part, and it was for this reason that the common rule $W H = R.s$ was unsatisfactory, for it did not take into account the weight of the pile, and consequently in the case just considered where W, H, and R are the same it would give the same value for s which, as Euclid used to say, is absurd. It was true that the heavier pile, by reason of its inertia and smaller set s, would experience a greater force on its head due to the blow and consequently elastic compression λ_p would be greater in its case, but the inertia was the cause of this.

The author largely agreed with Mr. Honeysett in regard to the effect when most of a wooden pile was in the ground. That meant further complications which endorsed the author's introductory remarks that the dynamics of pile driving was not the simple matter which at first sight it might appear to be. In the case of piles of ordinary length, about 20% of the load was supported by the toe of the pile. But in the case dealt with (a Simplex steel pile-tube) there was relatively little friction on the tube as the shoe was larger than the pile and thus left a clearance round the pile. He agreed that the determination of the time element was of great importance, and hence again the unsatisfactory nature of all formulæ as he believed none took the time into account.

In regard to the extrusion of the pile, the author had evidently not made the facts sufficiently clear. The autographic diagram obtained by means of the pile-set gauge showed a peak at the beginning. The left hand slope represented $\lambda + s$, and the right hand slope represented λ. These slopes were of slightly different inclination that on the right having the less slope. (Fig. 7, p. 168, IV., well illustrated the matter.) The time during which each of these slopes was drawn was very short (about 1/100th second) and very nearly the same, which meant that the elastic recovery λ of the pile and clay was practically as rapid as the elastic compression of these. But in addition to this, and not separately recorded by the autographic diagram was the elastic stretching of the clay adhering to the sides of the pile, for if the pile were left for a couple of hours after the last blow, then it would often be found to have extruded about two millimetres. This means that s as recorded by the diagram, or the usual direct measurement, of the first blow after a long rest, includes about 2 mm. which is not permanent set. If the blows follow each other at intervals of even a minute then the loss due to this slow extrusion is not incurred.

With regard to the discarding of h and p^1 in the hypothesis of the pressure of fluidity, this had been done because the " head " in the unloaded clay was so small in comparison with the load on the disc. It was also done as a simplification, and they would have been brought in again if the calculated results had seemed to indicate that the effect of h and p^1 was material.

Although so far as the author's and later Lordley's deeper experiments had gone, no effect of the unloaded clay had been observed, it seemed pretty obvious that such effect if any would take place long before the head was equal to the pressure of fluidity. It was certain, too, that long before the head was equal to the pressure of fluidity the sides of the hole would crush in, for in the author's model cliff experiment (IV., p. 155), this crushing occurred when the stress was only *one-tenth* of the pressure of fluidity.

As to applying the hypothesis, devised for clay, to metals, the author agreed it appeared daring, but it was merely a ' try ' which seemed worth making on account of the several beautiful agreements pointed out in the paper between other laws for clay and metals, and the results of so applying the hypothesis apparently entirely justified the deed.

He had already referred to Mr. Lane's suggestion in regard to the " piling " of the spheres. It was a great satisfaction to the author that so able a mathematician as Mr. Lane had not found anything radically wrong with hypothesis *re* the pressure of fluidity.

Mr. Unna stated that the formula $\frac{1}{8}$ W H = R.s had " not been found wanting," by which the author understood that piles safely stood the working loads put on them as the result of using that formula. This did not tell us how much more working load might have been safely put on them if we were more certain of the facts. The divisor of 8 was merely a factor of ignorance. A like argument could have been used (possible was) years ago in connection with several large masonry dams in Spain. They too had stood the test of time and not been found wanting in one sense, but we now know that in their cases about *half* the material could have been used if mixed with more brains and an even safer structure would have thereby resulted.

The percentage results recorded at p. 31 applied only to the particular conditions dealt with. They would probably be very different in different circumstances and each case needed separate treatment, so that it must not be assumed that the author's factor of ignorance would always be exactly half that of Sanders'.

The initially smaller pull required to withdraw a pile was probably due to the assistance at the start of the elastically stretched clay adhering to the sides of the pile. This might be looked upon as consisting of numerous small elastic threads which were stretched downwards by the penetration and were therefore tending to extrude the pile, and did in fact extrude it in some cases, as recorded by the author. When the pull was first applied the elastic threads contracted and helped the pull, but when the pile had been pulled up a short distance the elastic threads were stretched upwards and then opposed the movement of the pile and so increased the force necessary to withdraw it.

Mr. FitzSimons had also referred to effect of the inertia of the pile and the explanation he gave might also in part be true. The author agrees of course that energy cannot be destroyed, but in the present case, part of it was obviously rendered useless for driving purposes. A further illustration might be given. When one held a wooden ball say 2 ins. in diameter and hit it with a hammer a certain blow was felt by the hand. When the wooden ball was replaced by a leaden one of the same diameter and this was struck equally hard, the blow felt by the hand was much less.

The author had not yet read Goodrich on the subject. He had followed Prof. Boys's advice to him of not spending much time in reading, but to do experimental work instead. If this confirmed the work of others, especially if arrived at by different methods, useful work had been done. If it resulted in new facts so much the better and by good luck most of the author's results were new ones.

The author was pleased that Mr. Hiley supported him in regard to the effect of inertia. Mr. Hiley might be right about the division of λ into λ_p and λ_c though as λ was measured and λ_p was calculated from the dimensions and material of the pile and the force of the blow, there was not much room for a question of opinion. In regard to the author's two values for F, Mr. Honeysett had shown how these might be calculated to be equal. The author could not claim a 10% accuracy in connection with forces involved in pile driving. He hoped, however, his results were less inaccurate than those of most of the 39 authorities named by Prof. Henry Adams!

Mr. Becks in his closing remarks said he did not see his way to compare the results obtained by experiments with clay with those similarly obtained with metals, but some of the results now first published were not in the advanced copies of the paper; had they been, perhaps Mr. Becks would have been convinced.

The author had already referred to the improbability of there being much compression when making an experiment to determine the pressure of fluidity.

There were also material differences between such an experiment and punching, for in the latter case, a hole slightly larger than the punch was provided beneath the plate to be punched. Such ordinary punching was merely a case of shear, but in the case of the pressure of fluidity, the specimen was placed on a solid hard steel plate without any hole and the bottom of the specimen was flat before and after the experiment, though it was not held in any way, except by the pressure of the punch-like disc.

Mr. Hiley had arrived by a logical method at 0·006 sec. as the period of deceleration of the hammer. This the author agreed with on the assumption made, and was pleased to see that it apparently, confirmed the time recorded by the autographic pile-set gauge. When introducing his paper, the author had drawn on the black-board two curves, one purporting to represent the velocity of the hammer during the period of 0·0124 sec. (and the movement $\lambda + s$) and the other that of the pile head during the same period. These showed that, owing to the relative movements of the mass centres of the hammer and pile *after* these bodies were in contact and due to their elasticity, these velocities were *not* equal except at two points, one where both bodies were in motion, and the second at the end of the period 0·0124 sec. when both were momentarily at rest. If, therefore, the acceleration and deceleration of the head took place in equal times the deceleration occupied 0·0062 sec. As the hammer and head were in contact during the period 0·0124 sec. their mean speeds must have been the same.

By another method of calculation, Mr. Hiley obtained 130 tons as the value of R. This was considerably less than the author's value, but at least confirmed the latter's opinion that the value of R given by the equation W.H. = R.s was far too large. Mr. Hiley seemed to doubt the possibility of measuring the duration of the blow accurately. On the autographic diagram 1/10th second was represented by about 15 cm., so that 1/100th sec. was represented by about 1·5 cms. = 0·59 in. an amount which was easily scaled.

To try to do without the time element by introducing *e* the co-efficient of restitution, seemed merely replacing one difficulty by a greater one, for to determine *e* it was necessary to measure the height or velocity of rebound of the hammer after it had struck the pile head.

With Mr. Geen's written contribution, the author was in accord, especially the point that piles have to be strong enough to withstand being put into the place ready for their life's work, and that if they were strong enough for the former they would be amply so for the latter.

Monday, April 9, 1923.

Mr. G. A. Becks, A.M.I.C.E., Vice-President,
in the Chair.

THE WORK OF THE LABOUR CORPS IN FRANCE DURING THE WAR,

With Particular Reference to the 178 Labour Company.

By T. Exley-Fisher, M.S.E., P.A.S.I., A.M.Inst.M. & Cy.E.

The Labour Corps was formed towards the end of 1916.

Previous to the formation of this Corps, labour was mainly performed by A.S.C. and R.E. Labour Battalions, and infantry fatigues.

The two main objects of the Labour organisation were:—

1. To release the fighting soldier for his legitimate work.
2. To assist the Services and Departments to carry out their tasks.

The unskilled labour in France included the following categories:—

(*a*) The Labour Corps, including—
  (i.) Labour Companies.
  (ii.) Divisional Employment Companies.
  (iii.) Area Employment Companies.
(*b*) Canadian Labour Battalions.
(*c*) Middlesex (alien) Labour Companies.
(*d*) South African Native Labour Corps.
(*e*) Cape Coloured Battalion.
(*f*) Egyptian Labour Corps.
(*g*) Chinese Labour Corps.
(*h*) Fijian Labour Detachment.
(*i*) Indian Labour Corps.
(*j*) Non-Combatant Corps.
(*k*) Prisoner of War Companies.
(*l*) French and Belgian Civilian Labour.

It is with Labour Companies (Section (*a*) (i.)) that the author was mainly concerned.

The Labour Corps Base Depot was at Boulogne. The detail of the war establishment of a Labour Company varied with the different categories of labour. For purposes of command, discipline and interior economy, Companies were collected in Labour Groups, for which a Labour Group Headquarters under the command of a Lieutenant-Colonel was provided.

Labour Groups were organised in order to meet the ever-changing requirements of the Service, Companies being added to, or transferred from, Groups without breaking the usual chain of command.

The War Establishment of Labour Companies (Section (*a*) subsections (i.), (ii.), (iii.)) were as follows :—

A Labour Company—

1 Officer Commanding (Major or Captain).
4 Subalterns.
495 Other Ranks.

Total 500 All Ranks.

A Divisional Employment or Area Employment Company—

1 Officer Commanding (Major or Captain).
1 Subaltern.
273 Other Ranks.

Total 275 All Ranks.

Labour Companies were self-accounting units. Generally they were considered to be Corps troops, but they did not move with the formations to which they were attached, with the exception of all Divisional and Army and Corps Headquarters (Area) Employment Companies (which were specially allotted to the Headquarters concerned for the distribution and employment of personnel and were not included in Labour Groups), and these moved with their respective formations.

As a rule, Labour Companies had their own transport. Medical attention was given by the Medical Officer attached to Labour Group Headquarters.

The Officer Commanding a Labour Company was a Commanding Officer, and as such could exercise full powers of punishment laid down in para. 493, King's Regulations, unless such powers were restricted by the Officer Commanding a Labour Group. The latter authority had power to restrict the Company Commander to awarding a maximum of 7 days in the case of Field Punishment No. 1 and No. 2 and forfeiture of pay under Section 46 (2) (*d*) Army Act.

The medical category of men in Labour Companies was B2 or lower, and a large proportion of men were ex-line men who had been wounded.

Labour Companies (*a*) (i.) and Canadian Labour Battalions (*b*) were mostly employed in forward areas, the remaining categories being employed in back areas and at the base. Canadian Labour Units were permanently allotted for work in the Canadian Corps Area.

The work comprised a variety of tasks, some of them being as follows :—

- Light railway construction.
- Standard gauge railway construction.
- Roadmaking and repairs.
- Trench digging and defences.
- Duck board track repairs to the front line.
- Loading and off-loading ammunition, stone, timber, stores, etc.
- Filling shell holes.
- Salvage operations.
- Burial of the dead.

In the first instance Labour Companies were unarmed, but in the early part of 1918, on account of the military situation, Companies employed in army areas were fully armed. In August, 1918, three-quarters of the arms were withdrawn, leaving one platoon of each Company armed.

The normal working day was nine hours, exclusive of the time taken for meals and in proceeding to and from the place of work. This included 1½ miles distance from the place of parade to the place of work, and any time to march any excess distance could be deducted from the hours of work. For labour of low medical category the normal working day was 8 hours. Where the exigencies of the Service permitted, one day's rest in seven was allowed.

" Contracting " or task work was resorted to whenever possible. The men entered into friendly competition with each other, and a greater output in a shorter time generally resulted where task work could be employed.

The 178 Labour Company (originally known as the 1st Hants Infantry Labour Company) was formed at Taunton. At that time it was almost entirely composed of category men, the personnel varying from a Company Director to persons in the most humble walks of life. The Company proceeded to France on 6th March, 1917, under the command of Lieutenant (afterwards Captain) Roger Pocock, the well-known traveller (who is brother of Miss Lena Ashwell, of music and dramatic fame). After a brief stay at Boulogne, the Company moved to Hazebrouck, and for about a fortnight was engaged on standard gauge railway construction. The inclement weather of this period had the effect of placing twenty per cent. of these raw troops on the sick list. A move was then made to the Poperinghe district, and for about two and a half months the Company was employed under the Assistant Director of Light Railways, being associated with the Canadian and New Zealand Railway troops. During this time, construction of sidings and track was in progress at Westoutre, Reninghelst, Ellarsyde, Busseboom, Ouderdom, Willesden Junction, and other places. Maintenance work was also executed. The ballasting of these light railways was mainly done with sand from Dunkerque. Wooden sleepers 4 ft. 6ins. long were mainly used in this construction, and the rails were spiked to the sleepers. The author regrets that he is unable to give definitely the weight of rail per yard, but he believes it was 20 lb. The joints were made with fish plates and four bolts. Culverts were made of timber, either square or rectangular in section, proportioned to the water courses they had to carry.

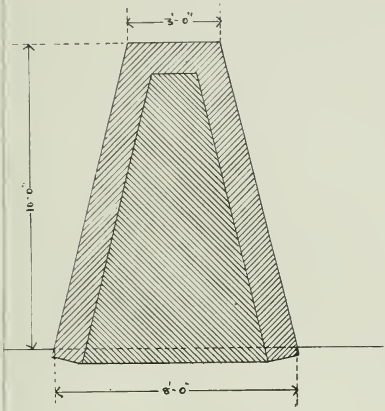
Although the Railway Troops were responsible for the technical side of the work, a considerable number of Labour Company men showed aptitude, and plate-laying gangs were formed for the more expeditious execution of the work. The author has in mind one sergeant in particular, who, although a warehouseman in civil life, made himself so proficient at his job that he was able to assemble and fix turn-outs without any supervision.

On 6th June, 1917, a large amount of light railway material was moved forward to Kemmel. At that time, and for some time previously, all kinds of rumours had been in circulation as to when the mines at Messines and Wytschaete would be exploded. With the taking forward of this material in conjunction with other circumstances, it needed only a little intelligent prognostication to judge that the crucial time was imminent. The mines exploded at about 3.10 on the morning of June 7th, 1917. At the moment of explosion the author was at Westoutre, some 5½ miles away. At this distance the report of the explosion was plainly heard above the deafening bombardment, and the concussion was very great indeed.

In the early hours of June 8th, 1917, work was commenced on the construction of a single line of light railway from Suicide Corner (on the Kemmel-Ypres Road) to Wytschaete. There was an existing Belgian metre gauge railway on the side of the Kemmel-Wytschaete Road, and, for the distance the new light railway followed the same direction, the permanent way of the metre gauge railway was utilised, the old rails being taken up and scrapped and new light rails spiked to the old sleepers. Where the new line of railway diverted from the road, embankments and cuttings were formed and new 4 ft. 6in. wooden sleepers laid. Sand ballast was used throughout.

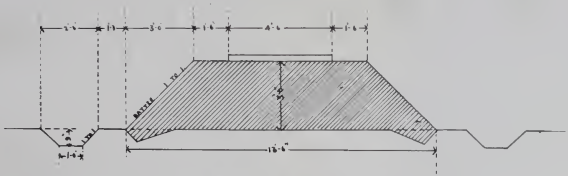
The line of railway passed fairly close to one of the mine craters. The railway was completed beyond Wytschaete Ridge on June 19th, 1917, the total length of about 5,500 yards having been executed in 12 days. The termination was within about 1,200 yards of the then new German front line.

FIG 4.



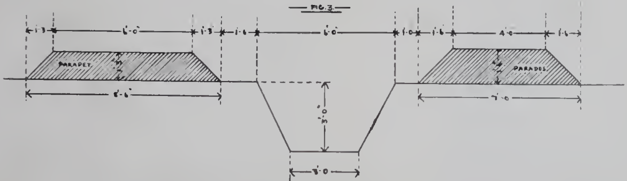
SECTION OF RIFLE RANGE AT HONDEGHEM.

FIG 1



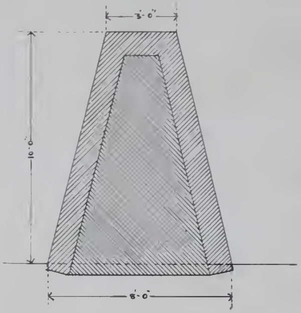
SECTION OF LIGHT RAILWAY FORMATION AT HALLEBAST.

FIG. 3.



SECTION OF DEFENCES IN THE HAZEBROUCK AREA.

FIG 4.



SECTION OF RIFLE RANGE
AT HONDEGHEM.

INCHES 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 FEET.

For the first few days of construction, there was little interference by enemy shelling, as he was consolidating his new position. After this the enemy artillery began to get busy. The latter stages of the railway were completed between the hours of 8 p.m. and 3.30 a.m. The author has a vivid recollection of this, as construction proceeded in front of our own 18-pounders which were firing at a low elevation. They fired five rounds rapid about every quarter of an hour, and during the firing it was necessary for everyone to lie down flat on the grade or in the ditches. It was understood that these guns were putting shrapnel over cross roads behind the enemy lines. Despite the activity of the " Bosche " artillery it is pleasing to record that no lives were lost on this work, and there were very few minor casualties. During the construction of a portion of this work, the Company was camped in a field on the north side of the Kemmel–Wytschaete Road about a 1,000 yards east of Suicide Corner. During the process of digging in for camp construction, at about 9 ins. below the grass surface of the field, some hard material was struck with a pick. On examination this proved to be a stoneware jar, which, however was shattered. The contents of the jar were a number of 16th century Spanish silver coins. It will be remembered that at this period, Belgium was under the dominion of Spain. It was impossible to determine how long the coins had been buried, but it must have been a considerable period, as if the land had been under the plough the jar and contents would assuredly have been turned up. In support of this, further excavation revealed the foundations of a building—probably a house—and a brick-steined well four feet in diameter and about ten feet deep was also found. A sample of the well water was submitted to the Sanitary Section, and it was stated that the water was fit for human consumption.

After the completion of the Kemmel–Wytschaete light railway a couple of days were spent in making a 200 yards' length of formation for a single line of light railway at Hallebast. A section of this is shown in figure 1. The author kept particulars of the time occupied with this, in order to ascertain the output per man.

These were as follows :—

185 men, 2 days of 8 hours each = 2,960 man-hours.
19,500 cubic feet earthwork in embankment.
1,575 ,, excavating in ditches.
———
21,075 total spoil handled,
equal to 7·1 cubic feet per man-hour.

After this, to July 19th, 1917, the Company was mainly engaged on the formation of earthworks for a switch road and bridge over the standard gauge railway about midway between Poperinghe and Brandhoek, on the north side of the Poperinghe–Vlamertinghe Road. The existing main road had deep side ditches for drainage purposes and at the two points where the switch road passed over the ditches it was necessary to culvert them in. This was done with circular corrugated iron culverts, 24 ins. in diameter. A large amount of excavating of spoil for formation was done, mules hauling scoops being largely employed. To a great extent the earthworks were consolidated by the passage of material thereover as the work progressed, but final consolidation was effected in the following manner. Substantial slabs of wood were laid down over a certain area of earthwork, and these were rolled with a twelve-ton steam roller. The road was then pitched with stone and rolled. The finishing coat was water bound macadam well rolled. Rough posts and handrails were fixed on each side of the road. Although the author frequently saw this road up to the end of December, 1917, he does not recollect that it was of much practical value—it was generally referred to as the folly of a certain officer of no inconsiderable rank.

For the next three months, the Company was engaged on a variety of work in the Vlamertinghe and Ypres district, including macadamising and tar-spraying to Poperinghe–Ypres Road; a plank avoiding road between Ypres and Kruisstraat Roads; macadamising of Kruisstraat Road; new standard gauge railway sidings at Vlamertinghe Station and Machine Gun Farm (near Ypres Asylum); and a new cour at Vlamertinghe Station. The ballast used for the railway sidings was débris from ruined buildings and that for the cour was new stone from French quarries. The stone used for surfacing and repairing roads was obtained from the same source. This latter material was fairly satisfactory in dry weather, but with heavy traffic and rain, speedy disintegration took place, which reminds one of an extract from *The Labour Battalion* (Capt. Maurice Drake):

> " We makes the roads, an' mends the roads,
> An' makes 'em all again.
> The traffic tears 'em all abroad, wi'
> one good shower o' rain.
> We scrapes off mud, an' strows our stone
> beneath the grinding wheels.
> The sweat runs down behind our ears,
> We'm muck from cap to heels."

Vlamertinghe Station was not a popular resort. The proximity of the cross roads made it a favourite target for the Hun. The author did duty there as Officer-in-charge of the Stone Sidings for a fortnight in October, 1917, at which time we were attacking at Passchendaele, and a large amount of stone was being loaded up for use on forward roads, and this was taken up at night. On occasions, 130 lorries were detailed to report at the Stone Sidings to take stone forward.

The following observation of time taken to load and off-load various materials may be of interest.

420	tons of sleepers, slabs, pickets and wire off-loaded from standard gauge railway trucks in 910 man-hours = 0·46 ton per man-hour.
460	tons of standard gauge railway sleepers (about 8,000 sleepers) off-loaded from standard gauge railway trucks in 720 man-hours = 0·64 ton per man-hour.
423	tons stone off-loaded from standard gauge railway trucks.
840	tons timber off-loaded from ditto.
300	tons stone loaded into lorries and G.S. wagons.
1,563	tons material handled in 2,000 man-hours = 0·78 ton per man-hour.
375	tons gravel off-loaded from standard gauge railway trucks in 147 man-hours = 2·55 tons per man-hour.

In regard to the last-mentioned item, it is only fair to state that the material was dumped on the ground from ordinary open trucks, whilst in the case of sleepers and other timber, these were in closed trucks which made the handling of the material very difficult.

For the next six weeks (which took up to the end of 1917) the work was road repairs in the St. Jean district, east of Ypres, the following roads being macadamised in whole or part :—St. Jean Road, Wells Cross Roads, Boundary Road, Junction Road and Savile Road. A considerable amount of maintenance was also done to Godley Road, which was a plank road. St. Jean Road, in common with many Belgian roads, had the central portion paved and the side margins macadamised. This pavé for the most part stood its mark very well indeed (although Flanders mud was the only foundation it had), but in very bad and hollow places no attempt was made to repair the pavé, but the whole of the roadway was macadamised in such circumstances.

At this time, the Boche was very active with his aircraft, and it was a common occurrence for a fleet of a dozen Gothas to come over in broad daylight and bomb the roads. In road work, getting rid of the surface water after heavy rains was a difficult job. The side ditches became heavily charged, and one's ingenuity was often taxed to find an outlet.

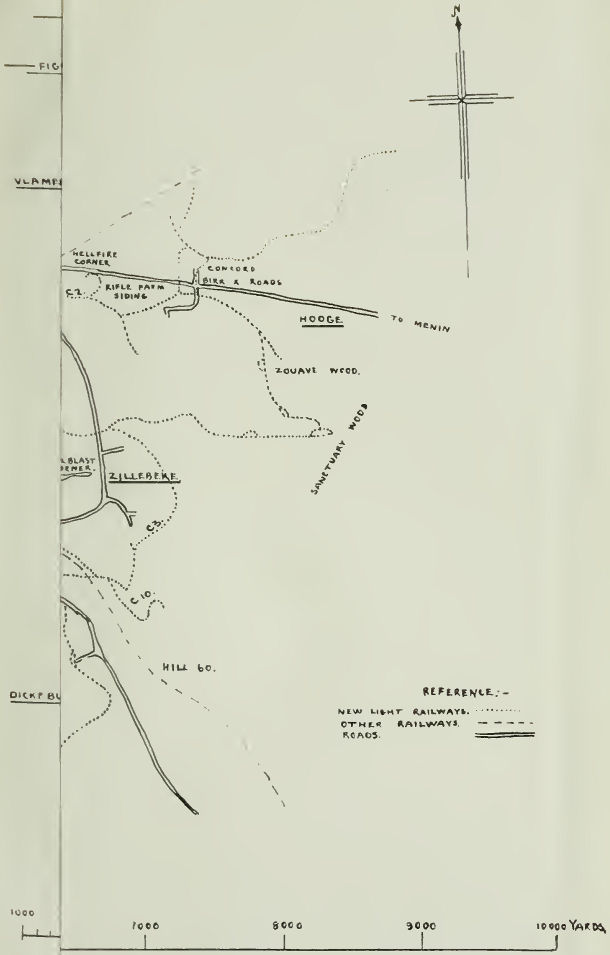
The first five weeks of 1918 were occupied in road repairs in the neighbourhood of Elverdinghe, Boesinghe, Het Sas and Carpentier Cross Roads. This was similar work to the last job. From this time to the end of April, 1918, the Company was engaged on the construction of a light railway spur at Hell-Fire Corner, and new light railway construction near Ypres Asylum, at Zillebeke and also at Boeschepe, as well as maintenance of the lines of light railway shown in figure 2. In maintenance work, material used for packing sleepers was débris from ruined buildings. The ever-increasing intensity of enemy shellfire made a great amount of work in repairing breaks in the track. Many of these lines of rail (instead of being constructed with wooden sleepers as previously described) consisted of lengths of rails bolted to 3 ft. 9 in. steel sleepers. This mode of construction enabled breaks in the track to be repaired in a minimum of time. During this period a considerable amount of light railway material was salvaged and conveyed to a dump at Hitchen Yard. The whole of these light railways were in an excellent state of repair when our retirement was made in the Spring of 1918. One of the last jobs the author had on light railways in the Salient was to take up certain portions of the track shown on figure 2. After this, about a week was spent in loading ammunition at Brielen Dump and X.C.B. Dump, near Poperinghe.

The following are typical particulars of time taken on this work :—

170 tons 18-pounder shells loaded into light railway trucks.
60 tons ditto off-loaded from ditto.
—
230 tons handled in 573 man-hours = 0·4 ton per man-hour.
310 tons 18-pounder shells loaded into light railway trucks in 564 man-hours = 0·55 ton per man-hour.

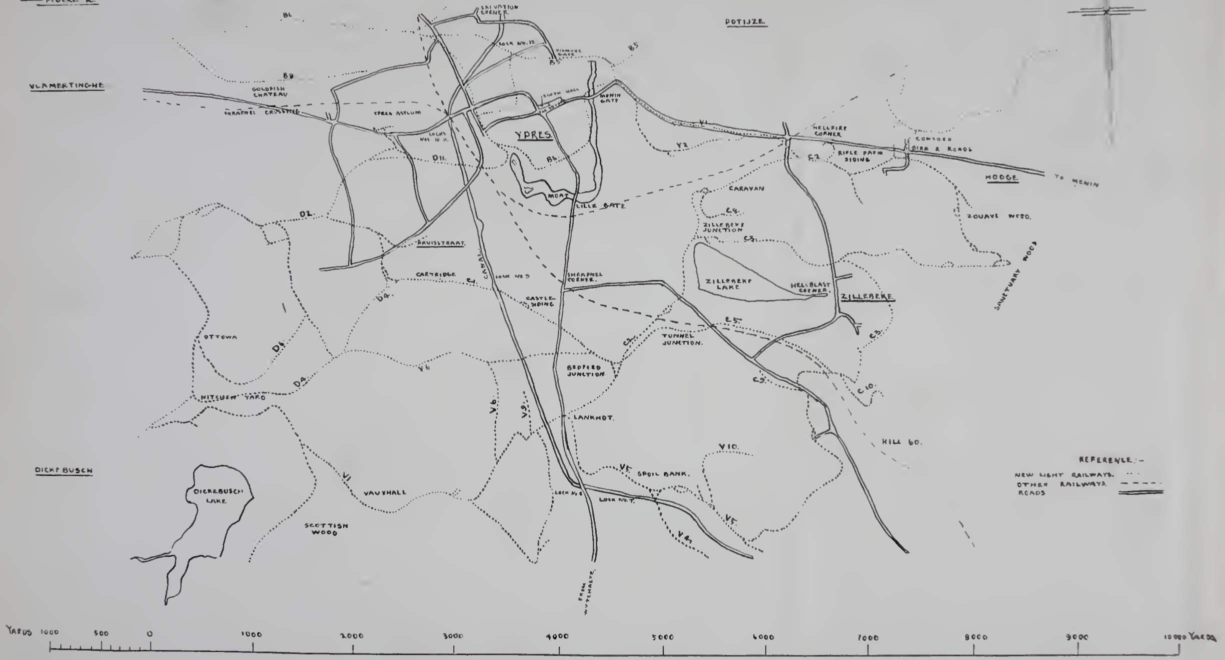
The author was then ordered to proceed to Hoymille, near Bergues, in command of a detachment of 100 other ranks. He and the personnel of his detachment were very thankful to take what proved to be their last view of the Ypres Salient.

The work at Hoymille was the construction of a railhead road on the standard gauge railway near the Heavy Repair Shops. The pitching of the road was of block chalk, which was rolled with a steam roller, and this was surfaced with a four-inch layer of broken stone and again rolled. No surface tarring was done. This job occupied just over a fortnight, after which the detachment rejoined the Company which was then located at Ledringham, and was engaged there on new


N
FIG
VLAMP
HELLFIRE CORNER
CONCORD
BIRR X ROADS
RIFLE FARM SIDING
C2
HOOGE
TO MENIN
ZOUAVE WOOD.
SANCTUARY WOOD
BLAST
RNER.
ZILLEBEKE
C3
C10
HILL 60.
DICKEBU
REFERENCE:-
NEW LIGHT RAILWAYS.
OTHER RAILWAYS.
ROADS.
YARDS 1000
7000
8000
9000
10000 YARDS

LIGHT RAILWAY MAINTENANCE (5 FEBY. TO 30 APL, 1915.)

FIGURE 2.



light railway construction. In this work, sand was used for ballasting the track, and wooden sleepers were used.

A move was made on May 29th, 1918, to Steenvoorde, and for about a fortnight the work comprised new light railway construction similar to that just mentioned. The work performed for the next seven weeks was defences at various places including Hondeghem, Hazebrouck, Wallon Cappel, St. Marie Cappel, St. Sylvestre Cappel and Zuytpeene, which comprised the formation of fire and communication trenches, breast works, strong points and shallow dummy trenches. These latter, after a certain amount of brushwood had been placed therein, presented an appearance of deep trenches when photographed from the air. A section of fire trench in grass land is shown in figure 3. Most of this was done as task work, one shift per man being to complete six lineal feet of trench, etc. A shift comprised the stripping of 129 superficial feet of turf where the trench, parapet and parados occur; the digging of 81 cubic feet of trench; the formation of parapet and parados with the excavated material; the re-placing of the turf on parapet and parados; and the formation of loopholes as required. (There were five loopholes in each bay.) The average time taken per shift was six hours. This amount excavated compares very favourably with the amount laid down in the *Manual of Field Engineering*, which is as follows :—

> " Working Parties and their tasks. With full-sized tools the average untrained soldier should excavate in ordinary easy soil the following volumes in each hour—
>
> 1st hour ... ... 30 cubic feet.
> 2nd hour ... ... 25 ,,
> 3rd hour ... ... 15 ,,
> 4th hour and after, up to 8 hours ... 10 ,,

On this basis, 100 cubic feet would be executed in a 6 hours' relief, and while the actual task in question is 19 cubic feet short of this, there is the turf stripping and re-laying, and the parapet and parados formation, in addition. In arable land, a similar amount of trench digging and parapet and parados formation was executed per shift. Where growing crops were on the land, portions were re-planted on the newly-formed parapet and parados, but generally without much success. The usual way of dealing with parapet and parados in arable land where no crop was growing, was to form irregular ridges and furrows as directed by the camouflage officer.

Where breast works were built, 60 to 80 cubic feet per man constituted a shift. In section, a breast work was similar to an inverted trench. Sometimes the faces were formed wholly of sandbags filled with spoil and the core filled with similar material, whilst in other cases the profiles were formed with pickets to which expanded metal was attached and spoil filled between the two profiles. In the formation of breast works, the filling material was usually to barrow, hence the less quantity executed per task.

A rifle range was constructed at Hondeghem, a section of which is shown on figure 4. The range had a frontage of 36 feet. It was faced with turf and cored with spoil.

When the Company was leaving this area, the author, who was in temporary command, received the following communication :—

> " I should like to place on record my appreciation of the excellent work done by the undermentioned Labour Unit whilst employed on Defence Lines under VIIth. Corps.
>
> 178th Labour Company.
>
> R. A. Gillam (Brigadier-General),
> Chief Engineer, VIIth. Corps."

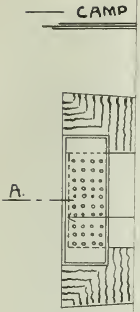
The next job was assisting in the construction of a plank avoiding road at Steenvoorde, on which the Company was engaged for about one week. On leaving the area, the author who was still in temporary command, received the following :—

> " Please convey my best thanks to your officers and men for the good work they have done during the short period they have been in my employ. I have also to thank you for the very great interest you have taken in the work and also in the welfare of your Company.
>
> W. L. Gibson (Major, R.E.),
> D.A.D. Roads, XIXth. Corps."

The Company then moved south to Lillers, and for over a month was split up in detachments and working as follows :—

Location.	Employment.	Employer.
Allouagne	Loading Ammunition ...	O.O.
Floringhem	,, ,, ...	,,
Pernes	,, ,, ...	,,
Burbure	,, ,, ...	,,
Locon	,, ,, ...	,,
Fosse 2 de Ferfay ...	Loading mine earth for standard gauge railway construction ...	R.C.E.
Fosse 4 de Marles ...	Loading mine earth for standard gauge railway construction ...	R.C.E.
Hurionville	Coaling locomotives ...	R.O.D.

The next two weeks were employed at Hinges (near Bethune) collecting wood for the Corps fuel dump ; filling shell holes ; and salvage operations. Another move was made and for five



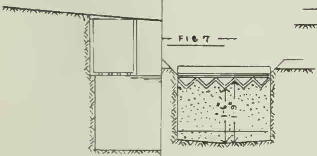
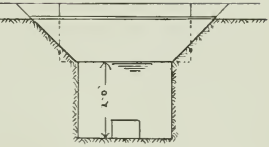


FIG 7

SECTION B.B.

FIG. 8.



SECTION C.C.

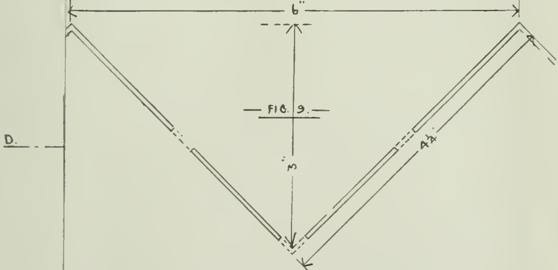


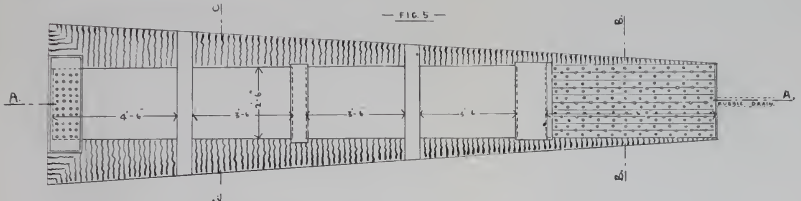
FIG. 9.

ENLARGED SECTION OF DISTRIBUTING CHANNELS TO ABLUTION WATER FILTER.

INCHES

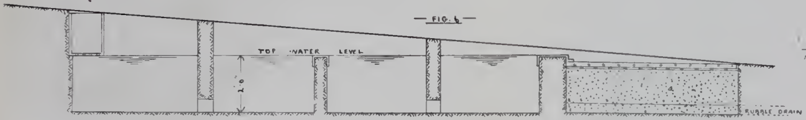
CAMP SEWAGE DISPOSAL.

FIG. 5



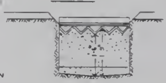
PLAN.

FIG. 6



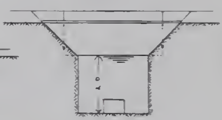
SECTION A.A.

FIG. 7



SECTION B.B.

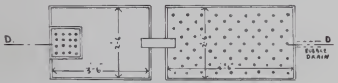
FIG. 8



SECTION C.C.

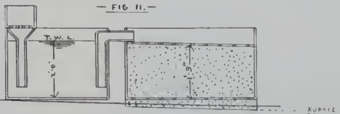
ABLUTION WATER.

FIG. 10



PLAN.

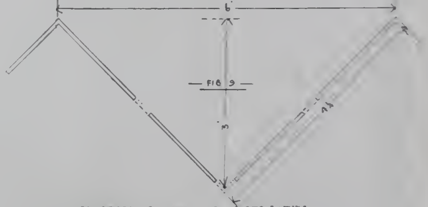
FIG. 11.



SECTION D.D.

COOKHOUSE WATER.

FIG. 9



ENLARGED SECTION OF DISTRIBUTING CHANNELS TO ABLUTION WATER FILTER.

months the work was standard gauge railway construction from Gorre ($2\frac{1}{4}$ miles from Bethune) to La Bassee, Lille, Orchies and St. Amand. The first five weeks of this took up to Armistice Day. The Boche, in his retreat, had very effectively destroyed the joints of the rails (and in many cases about midway between the joints), which necessitated the taking up of the old rails and the re-laying of new ones. The first portion of the work comprised the doubling of the track from Gorre to La Bassee. This originally was a double line but one set of metals and the sleepers had been removed at some period of the war. In some cases, where the rails did not appear to be damaged too badly, fish plates were fixed to enable the old length of rail to be used. An accident, fortunately without serious consequences, occurred in the following circumstances. On November 23rd, 1918, the works train had conveyed the parties to their respective destinations. At this time only one line of track was laid, and therefore on the return journey at night, the engine was pushing the train back to Fretin, where the parties were to be detrained. At Templeuve Station (France) the trucks had passed a certain point, but when the engine and tender reached this there was a violent rocking motion and the engine left the rails, it was brought to a standstill as soon as possible and this was done without any overturning. On investigation the cause was found to be a length of rail which had been patched with fish plates as just previously mentioned, the rail having spread with the locomotive passing over. This accident blocked the line for several hours.

After the Armistice, in addition to construction, an amount of time was spent in searching for and removing German mines under the track. German officers were brought under escort by British Intelligence Corps Officers to point out the positions of mines. All mines that were pointed out were safely removed, but towards the end of 1918, on a certain Sunday morning, when fortunately no working parties were out, a mine exploded near Nomain Station, and blew up a length of track. This was afterwards made good. Timber sleepers were invariably used, and flat-bottomed rails weighing 75 lb. per yard. The outsides of rails were secured to sleepers with coach screws and the insides with spikes. Some German construction near St. Amand Station had been carried out with steel sleepers.

Figures 5 to 11 give details of camp sewage disposal works laid down in at least one camp by the author. The works for dealing with ablution water consisted of four tanks excavated in the ground, having a total capacity of about 470 gallons. Over No. 1 tank, a receiving trough with perforated bottom was provided, and the trough was filled with loose straw, which latter was removed at least once daily and destroyed in the incinerator. The first tank is the largest one, having a capacity of about 140 gallons, the remaining three tanks being equal of about 110 gallons capacity. From the first tank, the sewage passed at floor level through the aperture in division wall to the second tank, and over the weir (which was made of biscuit tins) to the third tank, and the process was repeated until the percolating filter was reached. The weir between No. 4 tank and the filter was made of biscuit tins. The distributing channels of filter, V-shape, also made of the ubiquitous biscuit tins, had ⅜-inch holes punched therein. The bottom four inches of filtrant was composed of any hard material obtainable about the size of a golf ball, and the remainder was gravel or broken brick from 1 inch to ½ inch with a topping of finer material, which latter was renewed as occasion demanded. The amount of filtrant shown is 24 cubic feet. A rubble drain was made to convey the filter effluent to the nearest water course. In some cases, the levels would admit of only a twelve-inch depth of filtrant, whilst in others no channels for distributing the tank effluent were fixed. Despite the crudeness of these works, and although the amount of filtrant was disproportionate to the tankage, a good effluent was always produced. When a camp was evacuated, the tanks and filter were, of course, filled in, unless another unit was moving in forthwith. A handy navvy did the whole of the work required in the construction of disposal arrangements for ablution water. The waste water from the cookhouse was dealt with in a separate plant entirely above ground level. A box was made by the Company carpenter to act as a settling tank. This allowed for a two-feet depth of sewage, and had a water capacity of 110 gallons. A receiving hopper with perforated tray was provided, and submerged inlet and outlet pipes made of biscuit tins were fixed. The hopper was filled with straw as previously described. A further box was constructed to retain the filtrant, and holes were bored in the bottom for drainage, and the box itself stood on broken material to afford passage for the filter effluent. The media, 1 ft. 9 in. in depth, was hard material from 1 in. to ½ in. On the top of this a flat distributing tray (made of biscuit tins) was laid. This tray had ⅜-inch holes punched in, and had slight fall to induce better distribution of tank effluent. There were 20 cubic feet of media in this filter, the proportion of filter to tankage being much greater than was allowed for the ablution water. Filter effluent was conveyed to the nearest water course by means of a rubble drain. This arrangement, dealing with waste water from a cookhouse catering for an average of 500 men, produced a good effluent. In evacuating a certain camp, the author remembers a "scrounging" party from an adjacent camp, appropriating the cookhouse disposal arrangement, which had been a source of envy.

The Company ceased to exist as a unit in March, 1919, the undemobilised personnel being absorbed by the 129th Labour Company. The author was connected with the whole of the work performed by the Company from mid-April, 1917, to its demise. The Company, in common with other companies working in forward areas, passed through strenuous times and sustained numerous casualties. Several distinctions were won by men of the Company.

In connection with the importance of work performed by Labour Companies, the following order was issued in December, 1917, by a certain Corps Commander :—

> " The Corps Commander desires that every Officer, Non-Commissioned Officer and Man employed on roads, railways, tramways, mule tracks, duck boards and other communications in —th Corps Area, and on the construction of defences in the various rear lines of defence, shall be made to understand that it is on our communications, and on the work done behind the fronts that we depend in no small degree for the security of our front line.
>
> The numbers of Germans that we shall be able to kill, and the numbers of men that we shall lose, either in holding our line, or when the enemy or ourselves attack is directly dependent on the state of efficiency of our communications and back defences.
>
> The Corps Commander desires that this shall be impressed on the Officers of every unit now employed on such work or that shall come into the Corps Area in the future. He desires that the Officers shall make the object and the importance of their work clear to every man under their command, so that the men themselves may take a personal interest in getting as much work as possible done in the shortest time."

In conclusion, the author would like to express his high appreciation of the work carried out by the Labour Corps (which was really the Cinderella of the Service) and which perhaps has not received from some the full recognition due to it for its invaluable services.

Discussion.

Mr. Geo. A. Becks, A.M.I.C.E., F.S.E., said :—

It came, perhaps, with a certain amount of surprise to learn that there were, in France, during the War, such Corps as the Labour Corps, as the general impression was probably that every man who went oversea did so with the intention of fighting. It should have occurred to the speaker that this could hardly have been the case, as he himself was engaged as inspector of transport vehicles of every variety, including tip carts, handcarts, trench carts and the dozens of other classes of vehicles which obviously were not required solely for the transport of munitions.

As the Author's paper was largely historical there was little to discuss, but after reading it and examining the illustrations, the drawing of the sewage disposal tanks attracted his attention. Here, he thought, he had at least something which he could pick to pieces! This appeared to be an arrangement of septic tanks which for inefficiency had never been equalled. With a keen desire to find fault he anxiously turned to the descriptive matter, only to find that these were not septic tanks at all, for dealing with sewage in the ordinarily accepted sense, but were for ablution water and cook-house water, so that the wind was taken completely out of his sails.

The alternative method of discussing the paper was to do as was so frequently done in another place, namely, to ignore the author's paper entirely, and describe something else which had been done by the person speaking 30 or 40 years previously under much greater difficulties and with much greater success!

Mr. Becks did not, however, intend to adopt that course, as it was objectionable and irrelevant.

The main item of interest to the speaker was the prevailing note throughout the paper indicative that the author had turned his ability and talent to "making bricks without straw," to the utilisation of such material as he found at hand. Such ability should not be overlooked, as it brought out all that was best in an engineer, and it was with the greatest pleasure that he now called upon the meeting to pass a hearty vote of thanks to the author for his extremely interesting paper.

Mr. L. T. Godfrey Evans, M.S.E., expressed the pleasure of hearing the paper, and of how successfully the arduous work of the Labour Battalions had been on the great variety of duties allotted to them. The output of work seemed to have been fairly good—especially in the loading and unloading of material—and the same remark might equally apply to the excavation work, where much would depend upon the nature and character of the strata, for instance, on fairly soft ground, a cubic yard per man hour might be accomplished, and with a fairly large gang of workers with pick and shovel preparing a trench in a systematised manner, as for instance the reception of water mains, when the amount of excavated material of each worker per section of trench was divided up into subsections between the workmen, so that each might have the same amount of work to perform. The rear-most worker on attaining to the required depth of trench at once advanced to take up a new subsection at the front of all the workers for excavating a similar length of trench, and so on, for each rear man, in turn completing his subsection, advanced to the front for continuing the work on the trench. This system gave good results. At the same time, he appreciated the quality of the work done by the Labour Battalions, and that the figures mentioned by the author compared well for untrained soldiers, as given with the Manual of Field Engineering, but it was to be expected that better results were obtained from navvies skilled in trench work.

REPLY.

The author, in reply, said that he was obliged for the thanks and kind manner in which his paper had been received.

His original intention was to write a paper of about 2,000 words for publication in the journal, but the Secretary had suggested that the paper be enlarged to 4,000 or 5,000 words, and read and discussed at an ordinary meeting.

He was afraid that much of the matter was what might be termed of domestic interest, but if any useful purpose had been served he was more than gratified.

With regard to the Chairman's remarks on carrying out work with any material obtainable, it has been truly written :—

> " To be a success at the front, a man has to live by his
> " wits, and learn to make use of whatever is available, so that
> " from his knowledge of suitable types he may fashion some-
> " thing which will answer the need of the moment."

In regard to the disposal of ablution water, the initial difficulty was in deciding what was the average daily flow, and another difficulty was that it was not known how long a body of men might be located in one camp—it might be a couple of days, or as many months.

The daily flow of ablution water might be anything from 480 gallons to 1,124 gallons per 24 hours. If one-seventh of the company was resting per day, the daily flow was estimated at the lower figure arrived at as follows :—

	GALLONS.
Morning ablution water, 500 men at 3 pints each	187
Evening do. do. do.	187
Rest party, washing garments, 71 men at 1½ gals. each	106
Total	480

The larger figure was arrived at as follows :—

	GALLONS.
Morning ablution water, 500 men at 3 pints each	187
Evening do. do. do.	187
Washing garments, 500 men at $1\frac{1}{2}$ gals. each ...	750
Total	1,124

In the smaller flow, the settling tanks have a capacity of 24 hours, and on the larger flow a capacity of 10 hours.

In the smaller flow, the percolating filter dealt with tank effluent at the rate of 540 gals. per cubic yard of filtrant, and on the larger flow at the rate of 1,265 gals. per cubic yard of filtrant.

Of course, either of these volumes was grossly excessive, but in spite of this, a good effluent was produced as stated in the paper.

In answer to Mr. Godfrey Evans, the amount of material handled per man hour was an average for the whole of the men employed on the particular job, and this included any time taken in sheltering from hostile fire.

Monday, May 7, 1923, at 5 p.m.

MR. A. STEWART BUCKLE, M.INST.C.E., VICE-PRESIDENT, IN THE CHAIR.

PNEUMATIC HANDLING OF LIQUIDS.

By PIERRE MAUCLÈRE, M.Soc.Ings.Civs. (France).

THE object of this paper is to explain the general lay-out of a plant and the working details of a pneumatic apparatus invented by the author for the purpose of handling liquids generally, and more particularly those of an inflammatory nature, such as petrol, paraffin, alcohol, ether, benzol, light and heavy oils.

CONTROLLING PRINCIPLE.

The problem to be solved may be stated as follows :—

To ensure, by means of a series of twin pneumatic pulsators, the continuous flow of a liquid from closed tanks to others, regardless of their shape, size, or position, the interior of the tank remaining under atmospheric pressure, whilst preventing the liquids, during the process of receiving or delivering supplies as well as during the rest periods, from coming into contact with the atmosphere, thus doing away with the loss due to evaporation.

PULSATOR GROUPS.

Each of these groups consists of a battery of two units, hereinafter referred to as "gaugers," and capable of reversing their action. They operate by suction and delivery, and may be compared to twin single acting pumps, in which the displacement of the piston is replaced by expulsions and intakes of a gas* acting alternately and automatically in one or the other of the two units. The author's pulsator groups have been designed to comply with the following six conditions :—

(1) The time necessary to fill the gauger with liquid must be less than that occupied to empty it.

(2) The gauger, once filled, must remain so, however long the wait may be, until the reverse action is in progress, when, in turn, it will empty itself.

(3) The rate of the discharge of the liquid from the pulsator groups outlet should not show an appreciable interruption or depreciation at the moment of reversing the action of the gas in the two gaugers.

(4) The reversing, whatever the change in the rate of delivery may be, should always take place at the precise moment when the level of the liquid in the gauger which is being emptied has fallen to a level previously determined.

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* In the following pages the general term "gas" is used for the mixture of air and vapour of the liquid handled.

(5) It should be possible to regulate at will the rate of discharge from the delivery main, and even completely to suspend and restart by merely turning suitably placed cocks, without in any way interfering with the normal and automatic working of the group.

(6) The mechanism for reversing the action should always be in contact with the gas only, the parts in contact with the liquid being exclusively coppersmith or boilersmith work—floats, valves and pipes, that is to say, common and durable material.

General Principle of the System.

Fig. 1 shows diagrammatically the typical working details of the plant in which the liquids are handled in accordance with the author's principles. The only difference between the two sketches shown is that in the top one tank R is above the pulsators J_1 and J_2, while, in the lower one, it is at a lower level. This in no way interferes with the working of the apparatus, though, in the first case, the liquid in tank R would have the pressure due to its vertical elevation above J_1 and J_2 plus the vacuum in either of the latter when they are being filled. This would naturally ensure either J_1 or J_2 being filled quicker than they are emptied. The liquid is supplied in tank-wagon W from which it gravitates into the storage tank R by means of the pipe t_1. The air or vapour in tank R replaces the liquid in the tank-wagon W as the liquid flows from the former to the latter by means of the pipe shown. Once the tank-wagon W has been removed, and during the normal working of the plant, clack valve M admits air into tank R as the liquid from it is drawn away by the pulsators J_1 and J_2.

The compressed air is supplied by the compressor C, a_1 and a_2 acting as high and low pressure (suction) tanks. In the diagrams as shown, the high pressure from a_1 has direct access to J_2, which has been previously filled, thus forcing the liquid through valve r_2, and up the rising main t_2. At the same time, a_2, the low pressure tank, is in direct communication with J_1, which, in turn, causes it to be filled from tank R through the pipe t_1 and valve r_1. When all the liquid from J_2 has been forced up the rising main, the valves r_1 and r_2 are reversed, and the opposite action takes place, *i.e.*, J_2 is filled and J_1 is emptied. As the liquid from tank R is being drawn off, air is admitted from the atmosphere as required through clack valve M. This is an ordinary clack valve held in position by a spring, and can only open inwards to admit air when the pressure in the tank is less than that of the atmosphere, thus keeping the internal and external pressures to all intents and purposes constant.

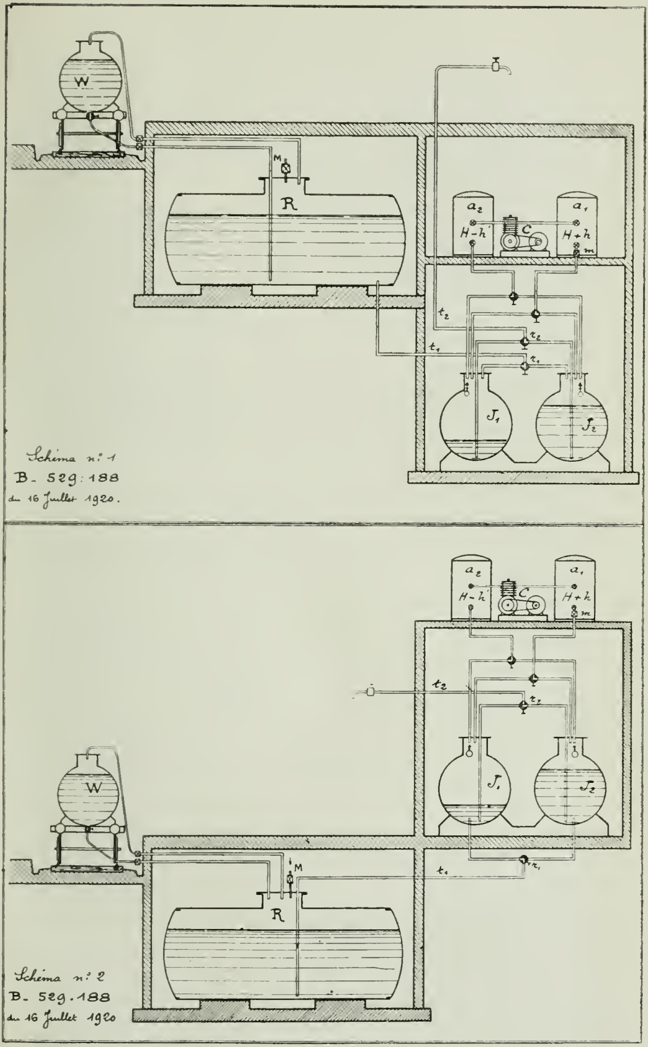

W
M
R
a_2
a_1
C
H-h'
H+h
m
t_2
t_1
r_2
r_1
J_1
J_2
Schéma n° 1
B_ 529:188
du 16 Juillet 1920.
W
M
R
a_2
a_1
C
H-h'
H+h
m
t_2
t_1
r_2
r_1
J_1
J_2
Schéma n° 2
B_ 529.188
du 16 Juillet 1920

FIG. 1.

Pipe line t_1 projects a few inches above the base of tank R, and the latter has at its lowest point a purge cock. This allows for the tapping off of water, grit, or any other impurity which may be supplied with the petrol, and thereby preventing it from contaminating the whole plant. If necessary, wire gauze can also be placed over this intake.

Reversing Mechanism.

The two types of pulsator groups hereinafter described have arrangements for automatic alternation, which are operated either pneumatically or mechanically. The pneumatic type is mostly advantageous in cases where, in view of local requirements, it is desirable to place it in some convenient spot somewhat removed from the gaugers.

Fig 2 shows the two types described. The one on the left is mechanically controlled, the one on the right pneumatically. The mechanically controlled unit has two similar tanks, J 1 and J 2, connected with the supply main by a pipe line in which are retaining valves and also coupled up with the delivery main under similar conditions. The top parts of the tanks J 1 and J 2 may be connected either with the general high-pressure (HP) or low pressure (BP) gas mains by means of pipes *t* 1 and *t* 2.

At the tank ends of the gas pipes are installed two floater valves *s* 1 and *s* 2, which automatically prevent the liquid from entering the pipes at the end of the second period. The pipe lines *t* 1 and *t* 2 connect with the reversing mechanism K, which consists of a double-acting piston in a cylinder. At the end of its respective strokes, the piston alternately connects one of the tanks J 1 and J 2 with the high-pressure main HP for conveying the liquid from the tanks into the discharge pipe line, and the other with the low pressure main BP for the intake of liquid into the tank by suction from the supply pipe. The piston is propelled by floats F 1 and F 2 acting on it by means of levers L 1 and L 2. The stroke of the piston takes place each time the liquid in J 1 and J 2 comes down to a certain pre-arranged level.

The lay-out for the pulsator groups with pneumatic reverse is similar, with the exception that the discharge of the liquid takes place through the regulating bell chamber B. The alternate supply of high and low pressure gas to the tanks J 1 and J 2 is regulated by means of the pneumatically operated reversing gear shown in section at the top right hand corner of the sketch. This consists of two symmetrical distributors *b* 1 and *b* 2 and their corresponding controlling gear C 1 and C 2. Each of the distributor cylinders is tapped midway longitudinally by pipes *t*′1 and *t*′2, which establish, according to the respective positions of the piston, a direct connection between the gas mains HP and BP and the pipes *t* 1′ and *t* 2′, as the case may be. The control-

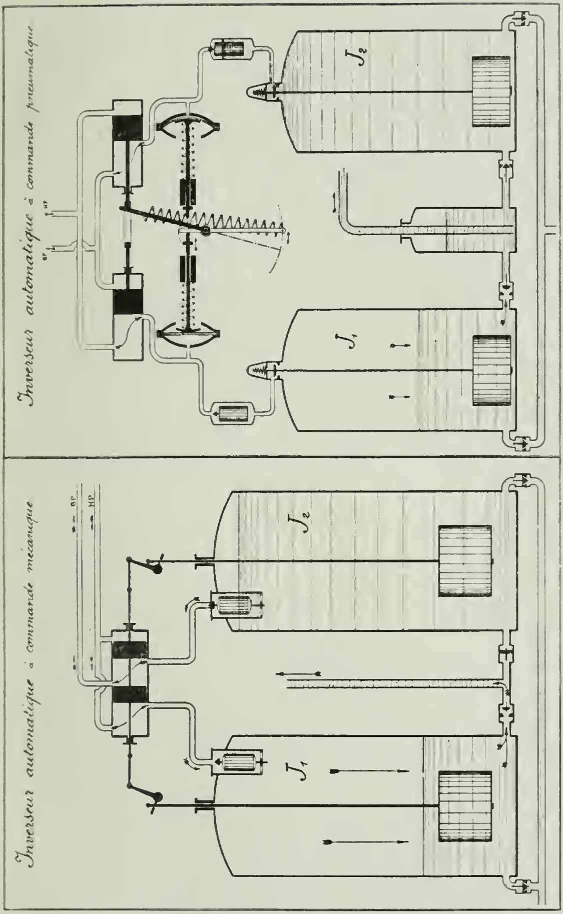

Inverseur automatique à commande mécanique
Inverseur automatique à commande pneumatique
J_1
J_2
J_1
J_2
BP
HP
BP
HP

FIG. 2.

ling parts C 1 and C 2 are laid out beneath their respective distributors, and are symmetrical and connected with the pipes which go from each element of the pulsator group to the corresponding distributor. Each of these control units is hermetically sealed by means of an elastic diaphragm *m* 1 or *m* 2, on which, by means of a spring, acts a plunger fixed on the end of rods *f* 1 and *f* 2 moving in bearings. On a pin O oscillates a lever L alternately in contact with one or the other of the plunger rods *f* 1 and *f* 2. To this lever is fixed one end of the spring R, the other end of which is attached near the extremity of the second lever L′. This latter lever is not otherwise connected with the lever L, but oscillates also around the same pin O. The free end of L′ fits in a slot *g* cut in the common connecting rod of the two pistons *p* 1 and *p* 2. Supposing, as is shown in the sketch, the pipe lines from the gauger J 1 to be in direct connection with the main HP, the diaphragm *m* 1 takes up a set position under the combined action of the gas pressure on one side and of the spring pressure on the other, as long as the discharge of that gauger-tank is in progress. The lever L in contact with the end of the plunger rod *f* is practically at right angles to the said rod. On the completion of the discharge of the liquid from J 1, the automatic and sudden closing of the gas inlet valve *d* 1 causes an increase in the pressure on the left hand side of the diaphragm *m* 1, thus expanding the diaphragm towards the right hand side. Consequently the plunger rod *f* 1 pushes to the right the upper end of the lever L.

In its movement the lever L, after reaching the position in direct line with the lever L 1, slightly over-reaches that line towards the left. This slight want of alignment causes the spring R to pull L′, which oscillates towards the left round the pin O, thus causing a movement to the left of the connecting rod *g* and also of the pistons *p* 1 and *p* 2, thus reversing the action of the gas in the pulsators. The series of strokes produces a continuous delivery of liquid, the regularity of which is ensured by the pressure of the gas in B, which is fixed on the delivery main. Naturally, for each type of the pulsator groups, the size of intake mains and the amount of vacuum in the delivery mains are so calculated that the filling of a gauger always takes less time than the emptying of it.

Industrial and Economic Considerations.

It will be seen from the foregoing explanations that it is possible, by means of pulsator groups automatically controlled, to stock and transmit liquids throughout a factory or depôt from one container to another, regardless of their size or position, the interior of the containers remaining at atmospheric pressure. Further, this is accomplished without liberating vapours into the atmosphere, and, thanks to adequately controlled dynamic action of a reduced and constant volume of gas operating in a complete cycle, such action is exercised in any convenient spot, either independently or simultaneously as desired.

The gas is set in motion by an electrically or mechanically driven compressor. The pneumatic transmission of the energy ensures, due to the perfect elasticity of the gas under latent pressure, the maximum amount of flexibility in the general working of the plant without any undue risk of water hammer.

The pulsator answers the same purpose as a pump without the disadvantages of the latter while permitting the automatic regulation at will of the rate of discharge, the latter amounting in some cases to several hundreds of cubic metres per hour.

With the method described it is also possible, by altering the pressure of the gas acting in the pulsator groups, to force the liquid to any height or distance desired by simply turning the cocks in the control office.

When the liquids to be handled give off at normal temperatures obnoxious, inflammable or poisonous vapours, the risk of accident is reduced to a minimum, due to the absence of drippings ; to the small number of working parts in contact with the liquid, and to the fact that the liquid does not come into contact with the free atmosphere, thus avoiding the possibility of evaporation. It can be definitely stated that, contrary to what at first might appear to be the case, wherever this apparatus has been installed a great economy in the original outlay, operating and running costs, and in the maintenance charges, have been effected, in comparison with the ordinary pumps previously in existence.

This is due mainly to the following facts :—

1. In cases where inflammable liquids were being handled, not only have the risks of fire been practically eliminated, but the insurance premiums have been reduced. Where poisonous products have been handled the risk of accidents to the employees has been greatly reduced.

2. By means of a single central pneumatic plant as described it is possible to operate automatically and control as many pulsator groups as desired, at any required rate of regular or irregular discharge, and regardless of their locality, such groups being of very simple and robust boilersmith construction, and very reliable in their working.

3. Further, the storage tanks may be placed in any desired spot and at any suitable level, thus reducing to a minimum the cost of the building work and foundations, and as the storage tanks are only subject to atmospheric pressure, their construction does not entail any special difficulty or extra cost, and there

is no limitation to their size, as is experienced when the internal pressure differs widely from that of the atmosphere.

APPLICATION TO CONCRETE CASES.

To form an accurate idea of the adaptibility of this apparatus to a large depôt, attention is drawn to Fig. 3, which shows a typical arrangement. It will be seen that the liquids delivered by the tank wagons W and V may be stored in the surface tank R, or in the underground ones R 1 and R 2. The pulsator group J 1, J 2 allows the liquid to be forced from the tank wagon W into the tank R, and also, by the mere manipulation of the reversing apparatus, to force the liquid from the tank R into a wagon, tank-lorry, or tank steamer, or, in fact, into any other suitable conveyance conveniently placed, should it be found desirable to make bulk deliveries from the tank R by road, rail, sea or other transport. The liquid supplied by the tank lorry V is decanted by gravitation into the tanks R 1, or R 2, the interiors of which are always at atmospheric pressure. The mixture of air and vapour replaces volumetrically the liquid in the tank wagon V as the liquid flows into the tanks R 1 and R 2. The pulsator group J 1′, J 2′ may feed from either of the storage tanks R 1 or R 2, and force the liquid either to the drawing-off points or filling posts B′ and B″ (shown on the right hand portion of the ground floor), fitted with automatic meters, and used for filling ordinary oil barrels, or else, to a can-filling shop, shown diagrammatically on the first floor.

In the latter shop are fitted a number of accurate filling meters D, D′ and D″, used to fill rapidly under pressure the ordinary trade cans. These filling meters consist of pulsating groups as before described, the internal capacity of which has been carefully adjusted, the controlling floats being also carefully set so as automatically to cut off the intake or discharge apertures as soon as the specified quantity has been taken up or discharged respectively.

The central air compressor supplying the necessary energy for the pulsator groups J1—J2 and J′1—J′2 and also for the can-filling plant D, D′ and D″, consists of a mechanically driven compressor C equipped with two regulating bell tanks A 1 and A 2, fixed on its intake and delivery mains respectively, and in which the compressor maintains pressure respectively higher and lower than the atmosphere.

Fig. 4 is a view of a pneumatic plant of average capacity. On the floor at the right hand side may be seen an automatic pulsator group worked by the pneumatically controlled reversing apparatus seen on the lower part of the larger of the two indicator boards on the left. In the far corner, on the ground, may be

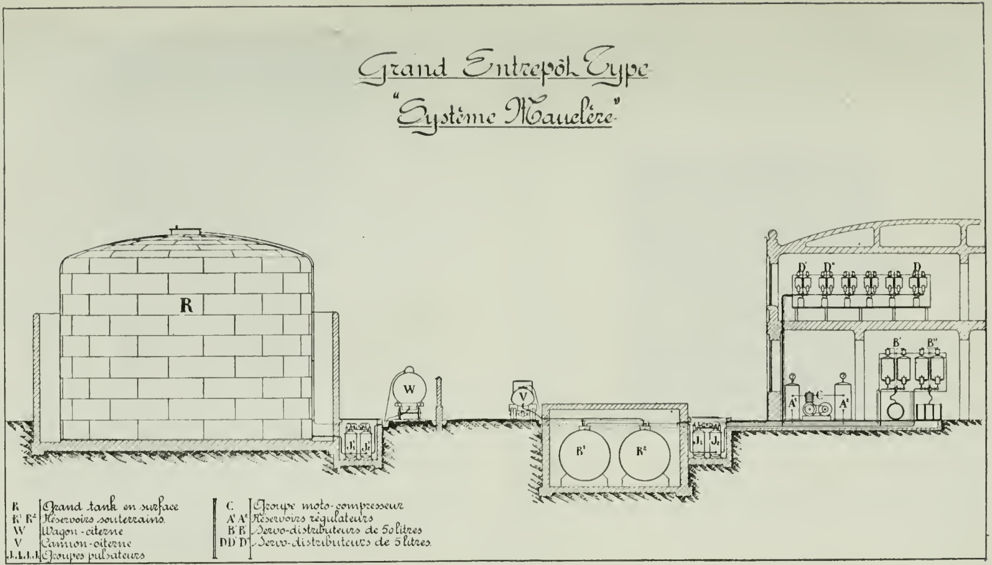

Grand Entrepôt Type
"Système Maucière"
R
W
V
J1 J2
B1 R2
D' D" D
B' B"
A1 C A2
R Grand tank en surface
R1 R2 Réservoirs souterrains
W Wagon-citerne
V Camion-citerne
J1 J2 J1 J2 Groupes pulsateurs
C Groupe moto-compresseur
A1 A2 Réservoirs régulateurs
B' B" Servo-distributeurs de 50 litres
D D' D" Servo-distributeurs de 5 litres

FIG. 3.

seen an electrically driven compressor, and directly above it the two regulating bell tanks. On the small indicator board are the pressure and vacuum gauges and the hand-worked regulating cock.

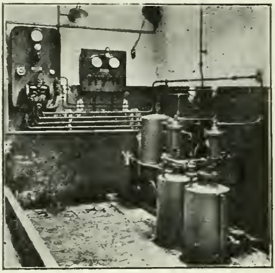


Fig. 4.

Fig. 5 shows the filling-room plant of a large depôt fitted with drawing-off points with automatic meters, which enable the rapid filling of vats (capacity 50 litres) conveyed on narrow-gauge trucks.

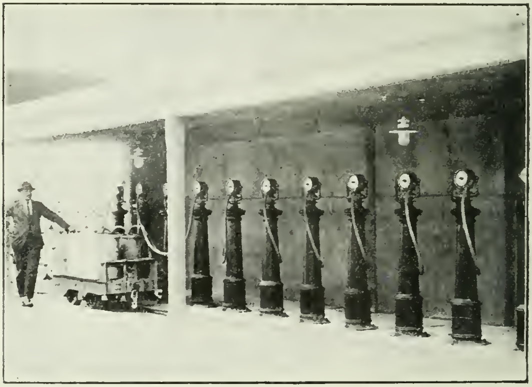


Fig. 5.

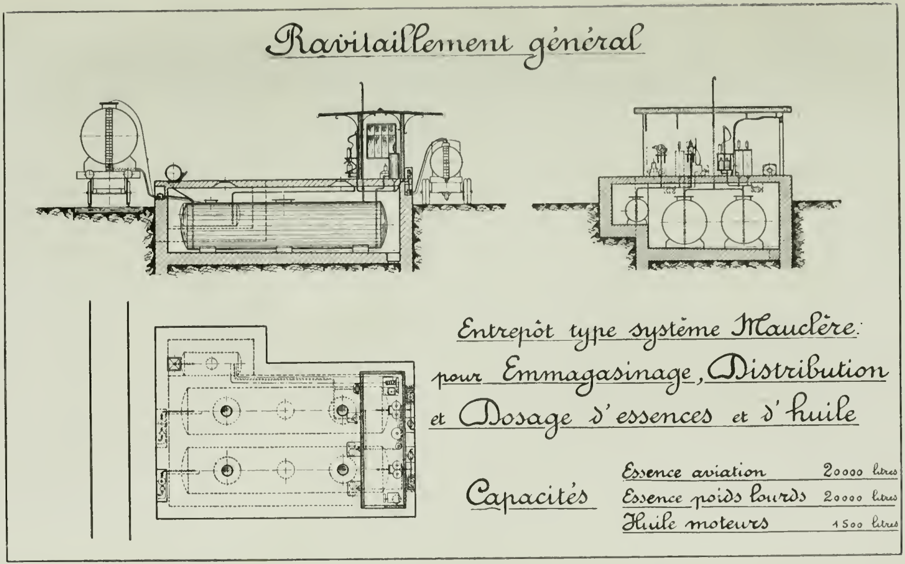

Ravitaillement général
Entrepôt type système Mauclère:
pour Emmagasinage, Distribution
et Dosage d'essences et d'huile
Capacités
Essence aviation 20000 litres
Essence poids lourds 20000 litres
Huile moteurs 1500 litres

FIG. 6.

1. Application to a General Supply Depot.

Fig. 6 shows the lay-out of a supply depôt or filling station in accordance with the author's method for the general handling of petrol and lubricating oil. In an underground chamber, the roof of which constitutes a loading platform, are two tanks of a capacity of 20,000 litres each. One of these tanks is used for aviation petrol and the other for ordinary commercial petrol, as used for motor lorries and the like. The lubricating oil is stocked in a tank of 1,500 litres capacity, placed in an elevated recess of the underground chamber.

The petrol is supplied to the depôt in tank wagons, which are shunted to a convenient position. Their contents are conveyed to their respective storage tanks by means of gravitation in the way already described. The lubricating oil is simply poured from its container into the 1,500 litre tank through a metal funnel. The petrol from each of the 20,000 litre storage tanks is extracted by means of two automatic pulsators housed in a small office building erected on the platform over the tanks.

Each pulsator group supplies two different filling posts, one for the filling of tank lorries or other receptacles of varying capacity where the delivery of liquid is measured by totalising meters. In the other the liquid is doled out volumetrically in fixed and constant quantities for the filling of barrels or cans.

A similar installation exists for dispensing the lubricating oil, one post for the filling of receptacles of various sizes, the oil supplied being measured by means of totalising meters, the other for automatically filling cans of specific size.

The apparatus is fixed to the walls and adequate protection is afforded against weather.

2. Application to Sugar Factories.

Fig. 7 shows the general application of the Mauclère plant to handling the liquors in a sugar factory.

Here there is a series of 10 pulsator groups all connected with the compressed air, vacuum and escape mains, issuing from a central pneumatic plant.

This plant consists of :—

1 compressor group delivering air at 5 kilogrammes per sq. cm.

1 compressor group delivering air at 3·5 kilogrammes per sq. cm.

1 vacuum pump able to ensure a minimum depression of 62 cm. of mercury.

Each of these units is equipped with bell regulating tanks, from which issue the gas mains.

The pulsometer groups handle the liquors in their different stages of concentration between their exit from the diffusing batteries until extraction from the vacuum pans of the quintuple apparatus. The drawing off of the condensation water from the evaporating boilers is ensured by means of four independent pulsator groups. The whole plant is characterised both by its great flexibility due to the facility with which the rate of discharge of any pulsator can be regulated at any moment and by

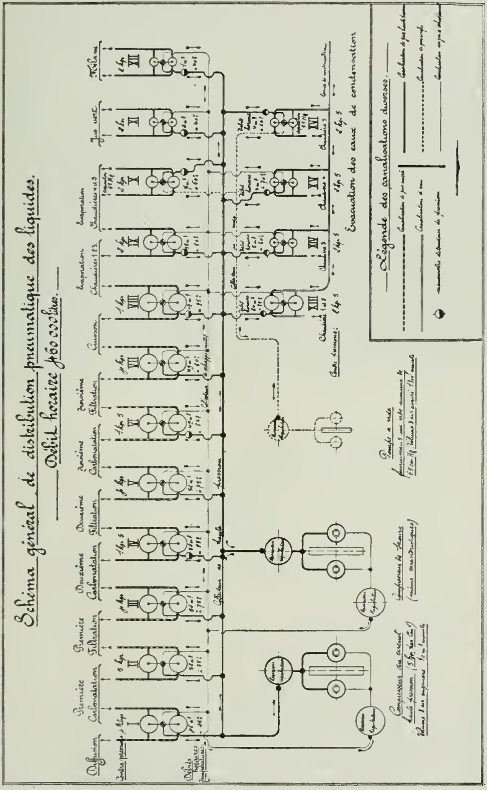

Sucrerie de Slatinany – (Tchéco-Slovaquie.)
Schéma général de distribution pneumatique des liquides.
Débit horaire 160 000 litres.
Diffusion
Première Carbonatation
Première Filtration
Deuxième Carbonatation
Deuxième Filtration
Troisième Carbonatation
Troisième Filtration
Cuisson
Évaporation Chaudières 1 & 2
Évaporation Chaudières 4 et 5
Jus vert
Mélasse
Contre-pression
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
XIV
XV
XVI
Collecteur de haute pression
Collecteur d'échappement
Évacuation des eaux de condensation
Compresseur du circuit haute pression (5 kg. par cm²)
Compresseurs de secours (mêmes caractéristiques)
Pompe à vide
Légende des canalisations diverses.

FIG. 7.

the efficiency of the pneumatic transmission of energy along the entire length of the gas mains, in which the drop in pressure is negligible.

3. Motor Tank Lorry.

Fig. 8 is a photograph of a motor tank lorry with Mauclère pneumatic apparatus for intake delivery and measurement of the liquid handled.

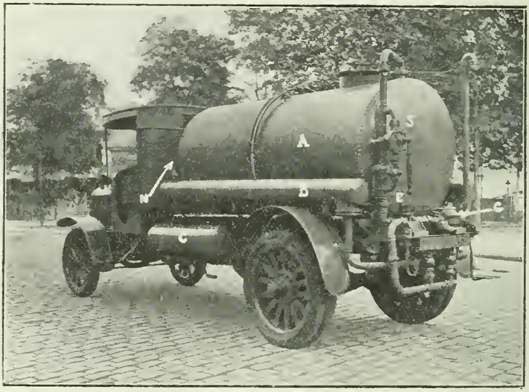


Fig. 8.

A is the storage tank.
B an element of the pulsator group.
C the air regulating bell, connected with the compressor, the latter being driven from the motor direct and not visible in the photograph.
N Cupboard containing pressure and vacuum gauges and also the pneumatically controlled reversor.
R the delivery main.
E regulating cock for intake and delivery mains.
G the totalising meter.
S the emergency hand pump.

4. Supply of Garages.

The previously described apparatus may be modified when applied to small installations, where the quantities to be supplied are not more than 40 or 50 litres at a time, which is the case with garages. Fig. 9 shows the lay-out of such a plant. The liquid flows through J by gravity into the tank A, which is maintained at atmospheric pressure. On the top of tank A is placed an intermediary one B, which operates in connection with the delivery gauger C. A compressor, either mechanically or hand-driven, produces the difference of pressure in the high pressure and

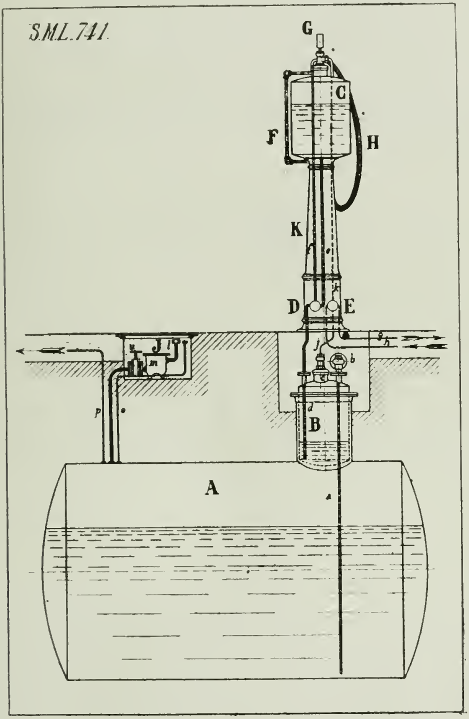


FIG. 9.

suction mains. These mains are linked up, and on the connecting pipe is a cock which is worked by hand. Turning the cock so as to connect B with the suction main, causes the intermediate tank B to be filled. After the completion of this operation, by a reverse movement, the high pressure is connected to B and the suction to C; this causes C to be filled. To empty C it is sufficient to reverse the cock and the liquid in it will be forced out under pressure during which time B will be refilled. When this hand-worked cock is in its intermediate position, neither pressure nor vacuum acts on the liquids. This type of apparatus possesses all the flexibility and safety of the larger ones.

5. Volumetric Retail Supply Gauges.

There are two main types of distributing gauges :—

(*A*) *Constant Volume Supply Gaugers.*

These are composed of two similar gaugers working alternately through the operation of reversing gear, either hand or mechanically driven. This arrangement is shown in Fig. 10. Their main characteristics are the accuracy with which the gauger cylinder is bored and the way in which any slight error in its construction is rectified by means of an adjusting device consisting of a metal rod passing through a boss in the side of the cylinder. The length of rod which penetrates into the interior is adjusted so as to give the desired volume with great accuracy. The floats which work the gas and liquid valves are not inside the gauger as in the previously described apparatus, but are in exterior chambers of reduced volume. The result is that any error in the level reached by the liquid, either in its upward or downward movement, causing the valves to operate, only affects a small quantity of liquid, and such quantity is negligible as regards the whole volume of each gauging. The top and bottom

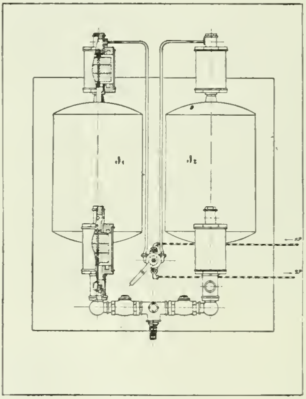


Fig. 10.

floats and the chambers in which they work are identical, consequently any variation in the level at which they operate the valve, due to variations in the specific gravity of the liquids, is the same at both the upper and lower ends, and consequently the error in the gauging is practically negligible.

When the liquid in a gauger is exhausted, the outlet valve closes, another valve, which is kept open by the pressure of the gas, is suddenly closed by a spring, and thereby stops any possibility of dripping. The result is that after carefully setting the gaugers by means of the adjusting rod referred to above, the supply of the exact amount of liquid decided upon is assured. The adjusting device, once set, cannot be tampered with except by taking great trouble, so that any possibility of fraud is obviated.

(B) Direct Reading Volume Supply Gaugers.

In order to comply with the requirements of the French Government regarding the official stamping of apparatus for the supply of petrol by volume to the public two types of gauge have been devised.

The data of the problem may be summarised as follows :—

1. To supply rapidly and easily any desired volume of liquid by means of gauges, which shall permit the movement of the level of the liquid dealt out under suitable pressure to be seen constantly on an officially stamped scale.
2. To insure the stoppage, slowing down or the restarting of the flow of liquid without the possibility of defrauding the consumer, if he follow the movement of the surface of the liquid.
3. To permit either the delivery of a pre-determined quantity of liquid or the determining of the volume of liquid delivered when the order to stop is given by the consumer.
4. To handle the liquid pneumatically without using pumps so that no moving or delicate parts of the mechanism come in contact with the liquid.

For realising this the author's direct-reading gaugers are so designed that the level of the liquid is made to coincide with the zero of the scale at the beginning of the operation. It then descends the scale during a delivery, no float or other piece of mechanism coming into contact with the liquid, thus doing away with the necessity of making corrections to allow for the volume of liquid displaced by them or for other similar disturbance.

The accurate coincidence of the starting level with the zero of the scale is ensured by means of an overflow pipe provided at the desired level. In order to avoid the presence of a float or other mechanism between the extreme points of the graduated scale, the gaugers are designed so that the emptying period is not ended automatically when the level reaches the lower end of the scale. It has to be stopped by the movement of a hand-worked cock reversing the pressure, thus obliging the operator to exercise great care.

These principles are applied in both types now to be described.

(*a*) *Volumetric Distributor with Twin Bodies.*—This comprises two gaugers J 1 and J 2 (Fig. 11), each provided with a graduated glass plate. The liquid enters the gaugers at the upper end and leaves at the lower end through a pipe connected with a float chamber, the purpose of which is automatically to stop the delivery before the gauger is completely emptied, should the operator forget to bring the reversing handle to its intermediate position when the dealing out is completed. The float would then fall and the emergency valve close.

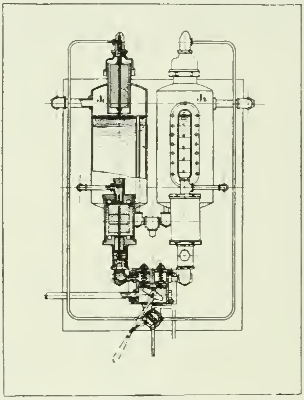


FIG. 11.

From the upper part of each gauger issues a gas pipe connected with the controlling cock. The aperture of each pipe may be closed by the action of a float valve when the liquid reaches a certain height above zero level. The control of the movements of both liquid and gas is ensured simultaneously by the movement of the handle of the control cock. The handle, by direct action, lifts, through its cams, one or the other of the valves of the outlet pipes, and by means of a connecting rod controls also the gas cock. When the handle is in its intermediate position the valves of the outlet pipes are closed, and the control cock is also in its intermediate position, so that the gas pressure exerts itself in both gaugers. Consequently, in the gauger where the level of the liquid is higher than zero, the overflow will act and the level will descend to zero, the gauger being then ready for service. Assuming, for instance, that the right hand side gauger J 2 is full to zero, by turning the handle towards it, the cam raises the valve, allows the liquid to be delivered from J 2, and the rod moves the cock so that there is pressure on the liquid in J 2, which is thereby expelled, while there is a vacuum in J1 which fills up. Alternate deliveries from J 1 and J 2 ensure very rapid deliveries of any given quantity of liquid.

(*b*) *Volumetric Distributor with Single Body.*—It comprises one gauger only (Fig. 12) with graduated glass plate. The liquid enters at the upper end and leaves at the lower end. It differs from the twin-bodied distributor in the arrangement of the overflow. The gauger is provided with a side chamber from which issues the overflow pipe returning the liquid to the tank, and to which is connected the pipe line for admission of the gas, controlled by means of a three-way cock. The valves closing the apertures of these two pipes are worked by the same rod, the movement of which is produced by the displacement of one float.

For filling the gauger the three-way cock is set so as to produce a vacuum in the gauger and in the side chamber, the delivery valve being closed. The gauger is filled to the zero level, after which the liquid flows into the side chamber until the moment when the float, by its upward movement, closes the gas pipe. The liquid continues to enter owing to the vacuum still existing in the gauger, and the level of the liquid rises in the side chamber. This process continues until the reduction in the volume of gas at the top of the gauger is such that the pressure is increased to a point at which the liquid cannot be drawn up any further. Obviously, this stoppage must take place before the liquid in the side chamber reaches the zero level, and the apparatus is so constructed as to ensure this. The gauger is then full and ready to deliver from zero downwards.

If, by operating the delivery valve and the three-way cock, gas under pressure is admitted to the gauger, a rapid delivery is ensured, and at the same time the liquid in the side chamber is returned to the tank.

6. As applied to Tank Steamers.

The majority of these are equipped with steam pumps placed amidships and fed from the main boilers generally near the stern. The handling of liquid by such means is costly, due chiefly to condensation in the long steam main and loss of pressure. The initial cost is great owing to the cost of steam pipes and their insulation. The author's apparatus overcomes these difficulties, whilst retaining the general advantages which it procures in land application, besides eliminating all loss and danger of fire due to leakage at the pumps. The central battery of pulsators occupies about the same space as the pumps. The initial outlay of one of these plants compared with steam pumps of similar capacity is estimated at 40 per cent. less.

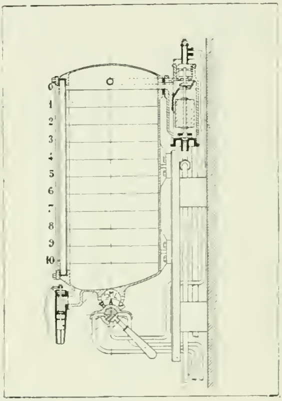


Fig. 12.

7. Firing Boilers.

The apparatus is equally adaptable afloat or ashore for automatically supplying oil to liquid fuel burners or feeding Diesel or semi-Diesel engines.

8. Military Supplies.

The apparatus which we have described is adaptable to military requirements, and particularly so for mobile troops. The consumption of liquid fuel by various artillery, Air Force and motor transport formations was considerable during the last war, and it is certain that it will be much greater in the next.

It may be said that the capacity for observation and bombardment, and rapidity of manœuvring a modern army depends on the rapidity, activity and regularity with which it is supplied with liquid fuel.

During the 1914-18 war the French armies were supplied by means of metal casks and cans distributed from station stores through the intermediary of regulation stations. Considerable difficulties often resulted in the collecting and returning of empty cans, which blocked parks and lines of communication before they were able to be returned to the Army zones depôts. During certain periods of long and active operations the manœuvring of the Allied Armies nearly failed of accomplishment on account of those difficulties. It is, consequently, advisable to foresee means of more modern transport, having in mind what has been learned by past experience and recent industrial progress.

The large Area Depôts (military depôts in peace time or requisitioned civilian depôts) would forward to the regulating stations, for Army requirements, trains or sections of tank wagons containing the various kinds of liquid fuel or lubricants required for general use.

From the regulating stations these tank wagons would be distributed as required among the various supply stations of the armies where the emptying of the tank wagon and the filling of the various receptacles (tank lorry, vats or cans) of the army operating in the corresponding section would take place. Obviously, to accomplish this programme it is necessary that the emptying and filling apparatus in the supply stations should be capable of ensuring a quick supply, whilst they must at the same time be so constructed as to allow of being taken down, transported and re-erected without loss of time, according to the movements of the army. The author recommends for this purpose the use of semi-fixed pneumatic apparatus, designed and constructed, and consisting, on the one hand, of detachable pipe lines laid out in series, with mobile pulsator groups and gauges ; and, on the other, of small pneumatic pressure generating plant, mounted on trailers, and accompanied by a motor-compressor unit of 8 to 10 H.P., with a control board, regulating receivers for high and low pressure and couplings for the corresponding pipe lines. A number of tank wagons having been brought to some spot on a railway siding near a road, it should be easy to establish in a few hours a centre for supplying an army with liquid fuel and lubricants by assembling at this place several of the apparatus just mentioned. These may be brought either in a single wagon or in a motor tractor to which is hooked a trailer equipped as a pneumatic station. It is possible under these conditions to ensure during the day as well as during the night a quick supply under pressure, without delivering saturated vapours, either into tank lorries, casks or cans. It is certain that the adoption of these directing principles would diminish by at least 80 per cent. the number of vats or cans originally required, and by at least 50 per cent. the railway traffic necessary for the transport of liquid fuel and lubricants. It is not necessary to insist on the further economy which would result from the avoidance of losses due to leakage and evaporation, and which may be estimated at 10 per cent. of the total consumption of liquid fuel.

Up to a certain point the considerations named retain their value in peace time.

9. Saturated Vapours.

It will have been noticed that great care has been taken in the design of the above-described apparatus to prevent the diffusion into the open of the vapour emanating from the liquids handled. Such a precaution, in addition to giving great security, leads also to a considerable saving, especially when one deals with such liquids as petrol, benzol, alcohol, ether, etc., which emit vapours in very large quantities even at normal temperature.

The three accompanying tables (pages 109 and 110) give interesting information on this point.

Table 1 gives the vapour tension of various liquids under atmospheric pressure for temperatures from 10° to 40° C.

Table 2 gives for the same temperatures the corresponding weight in grammes of vapour saturating a volume of 1 cubic metre at atmospheric pressure, such weights having been calculated with the help of the formula at the foot of the table.

Table 3 shows the volume in litres of the liquid resulting from the condensation of the said weights of saturating vapour per cubic metre.

The magnitude of those figures is very striking and gives food for thought.

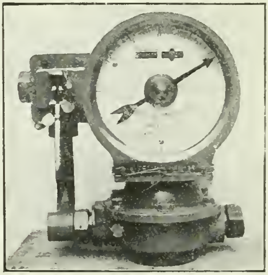


Fig. 13.

Totalising Meter.

Fig. 13 shows a meter of the author's design. The thumb screw in the centre is pulled forward, thereby disconnecting the pointer from the internal mechanism. This pointer is set to the figure which corresponds to the number of litres or gallons it is desired to supply, and the thumb screw is pushed in, thereby fixing the pointer to the internal mechanism. As the liquid is allowed to flow, the pointer indicates the amount supplied, *i.e.*, if it were set at 50, it would continue to turn backwards until it coincided with the zero mark, which it would not do until the 50 litres or gallons had been supplied to the customer E.g., if it were stopped at 10 the customer would know he had received only (50 – 10) = 40 volumes.

TABLEAU No. 1.

TENSIONS MAXIMA DE VAPEURS À LA PRESSION H = 760 MM. DE MERCURE.

Températures Centigrades.	Pentane. C^5H^{12}	Hexane. C^6H^{14}	Heptane. C^7H^{16}	Ether $(C^2H^5)^2O$	Benzène. C^6H^6	Alcool Éthylique. $(C^2H^5)OH$
10°	283	75·7	20·5	291	45	23
20°	420	120	35·5	442	74	43
30	611	185	58·3	647	117	78
40°	611	277	92	647	180	133

NOTA.—Les tensions ci-dessus sont exprimées en millimètres de mercure.

TABLEAU No. 2.

POIDS DE VAPEURS SATURANTES PAR METRE CUBE SOUS PRESSION H = 760 MM. DE MERCURE.

Températures Centigrades.	Pentane C^5H^{12}	Hexane C^6H^{14}	Heptane C^7H^{16}	Ether $(C^2H^5)^2O$	Benzène C^6H^6	Alcool Éthylique $(C^2H^5)OH$
10°	1 200	403	114	1 262	202	63
20°	1 738	624	196	1 818	318	114
30°	2 450	929	304	2 540	493	195
40°	2 450	1 348	466	2 540	730	321

NOTA.—Les poids ci-dessus sont exprimés en grammes par centimetre caré et calculés d'après la formule—

$$P = 1\,000\, d_t\, 1{\cdot}293\, \frac{F}{76} \cdot \frac{1}{1 + \alpha t}$$

TABLEAU No. 3.

VOLUMES DE LIQUIDES CONDENSÉS CORRESPONDANT AUX POIDS DE VAPEURS SATURANTES DU TABLEAU No. 2.

Tempéra- tures Centi- grades.	Pentane C^5H^{12}	Hexane C^6H^{14}	Heptane C^7H^{16}	Ether $(C^2H^5)^2O$	Benzène C^6H^6	Alcool Éthylique $(C^2H^5)OH$
10°	1·90	0·63	0·1	1·73	0·2	0·08
20°	2·78	0·98	0·2	2·5	0·39	0·14
30°	3·95	1·47	0·4	3·6	0·5	0·25
40°	3·95	2·14	0·6	3·6	0·8	0·42

NOTA.—Les volumes ci-dessus sont exprimés en litres.

DISCUSSION.

Mr. T. J. Gueritte, M.Soc. Ing.Civ., Past-President, said he felt indebted to the author for placing before the members the principles of the clever apparatus designed by him for the solution of a difficult problem. The description of the mechanical part of the plant was clear, although there were many details on which fuller information would have been welcome, had time allowed. He understood that the "gas" which was used for causing the movement of the liquid was the mixture of air (which would naturally be found in the apparatus) with vapour emanating from the liquid, which vapour would not be lost, seeing that the plant worked in a closed cycle. But, on other occasions, it might be that an inert gas was used, while, on the contrary, in special cases, it might be desirable to use a gas whose active chemical properties were beneficial. He would, therefore, like to hear more about the nature of the various kinds of gas used, and the reasons which lead to their adoption.

Capt. Richard Twelvetrees, A.M.I.Mech.E., M.I.A.E., M.Soc. Ing. Civ., Member of Council, said that having had some experience in handling large quantities of petrol, in connection with the automobile industry, he would ask the author a couple of questions. He noticed that in one part of the apparatus diaphragms made of rubber were employed, but in view of the well-known deleterious effect that petrol had on rubber, he would like to know how long these diaphragms lasted.

His second question related to the important subject of evaporation or shrinkage of the spirit, which in commercial undertakings had always to be submitted to, as so much loss.

According to the author no evaporation could occur in his apparatus; but, as a matter of interest, he would like to know what measures, if any, were taken to compare the amounts drawn from the apparatus with those put in—or in other words what check was provided to guard against evaporation losses in handling the spirit on a commercial basis.

Mr. David Bywater said he thought that the Mauclère System was somewhat intricate for the handling of light volatile oils, and experience showed that valves and other parts working in these oils were apt to get out of order.

There was, seemingly, no protection against the sucking up, from the bottom of the main tank, of impurities such as water, grit, etc., which must eventually pass into the tank of the motor car. There was always an objection to underground tanks having an air space above the petrol in store, owing to condensation and resultant collection of water. This condensation took place in all forms of tanks, and it was common for the rail or road tank wagons delivering the petrol to contain considerable quantities of water.

In the Mauclère System he saw no protection against the explosion of the vapours formed inside the tank, and the loss of this vapour, which was expelled into the tank wagon, was considerable, inasmuch as one volume of petrol evaporated into about 170 volumes.

He added, in conclusion, that there was a system, of English invention, which eliminated the above faults, and used water as the displacing medium instead of some "gas."

Mr. W. Noble Twelvetrees, M.I.Mech.E., A.M.I.E.E., M.Soc.Ing.Civ., Past-President, said although it appeared that the Mauclère System was intended primarily for dealing with liquids, such as petrol, it occurred to him that it might be employed for other liquids. He had in mind the case of natural mineral waters, the value of these depending, to some extent, upon the retention of the gas with which they were charged on delivery from the spring. The speaker wished to ask the author whether the system would enable such waters to be handled without material loss of the gas present in their natural state.

Mr. H. McFarland Davis, A.S.E., asked whether it were possible for the pneumatic control altogether to prevent loss of petrol by evaporation. Air would be admitted to the storage tank to replace volumetrically the quantity of petrol drawn therefrom. Presumably, if air could enter, petrol vapour could escape —a point which Mr. Richard Twelvetrees had touched upon.

Even if means were employed to admit air, and to prevent the simultaneous escape of petrol vapour, while the storage tank was being discharged, one expected that some vapour would be contained in the air with which the storage tank would be filled when its petrol content had been exhausted. While the storage tank was being replenished from a road tank wagon, the air in the storage tank (presumably containing a proportion of petrol vapour) would be returned to the road tank wagon. Could the author say with certainty that the air so returned would contain no petrol vapour ? On the other hand, if it did contain some such vapour a corresponding loss in volume of petrol must have been experienced. Was this loss measurable, and if so, what percentage of volume of petrol did it represent ?

Author's Reply to the Discussion.

(*a*) *The nature of the Gas used for the Propulsion of the Liquid.*—The gas used in the pneumatic handling of liquids, circulating in a close cycle may be, according to circumstances, either air or a gas complying with certain requirements. For instance, to handle inflammable liquids or those which are affected by exposure to the atmosphere, it is advisable to use an inert gas, *i.e.*, one which has no chemical action on the liquid such as carbonic acid gas, which gives an extra amount of safety. On the other hand, in the case of other liquids which are unaffected by the presence of air, or which do not give off inflammable vapours at ordinary temperature, such as sulphuric acid, milk, oils, etc., ordinary air may be used.

(*b*) *Loss of Liquid due to Evaporation.*—It is important to emphasise the fact that there is no loss of liquid in the form of vapour while the storage tanks are being filled, the air contents of the storage tanks, saturated with the vapour of the liquid at atmospheric pressure, passes into the tank-wagon, tank-lorry or the vats, to replace the liquid which flows from the latter. This liquid, being thus kept in contact with air already saturated with vapour, does not liberate the quantity of vapour which would issue from it during the emptying process if it were in contact with pure air. This result is due to the provision of the double line of piping, which allows exchange of saturated air between the storage tanks and the tank-wagon or lorry. The same considerations apply during the reverse operation of filling a tank-wagon or lorry from the depot tanks. The above theoretical views have received practical confirmation in the large depots constructed by the author, the quantities of liquid despatched from them tallying very closely with the actual quantity delivered into them. This is shown by the stocktaking and despatching sheets over a number of years. The saving accruing from this avoidance of loss of vapour is considerable, when handling volatile products, such as those mentioned in the tables at pages 109 & 110, where are shown the quantities of these liquids saturating one cubic metre of air at ordinary temperature. This complete saving of the saturating vapours cannot be secured in the system referred to by Mr. David Bywater, in view of the fact that when filling a tank-lorry or tank-wagon, it is necessary, with that system, to allow the free escape into the atmosphere of the vapour-saturated air they contain.

(*c*) *Separating Impurities.*—In a storage tank, solid matter as well as any water contained in the petrol, would accumulate in the lower part. In view of the fact that the end of the suction mains is always at a certain height above the bottom of this tank, and impurities settle below it, consequently they are not taken up. Ten years' experience in the working of several plants has shown that it was sufficient to clean the storage tanks out every two years, by means of a special suction pipe reaching to the bottom of the tank.

(*d*) *Wear and Tear of Valves in the Petrol.*—The author's reply to Mr. Bywaters on this point is that wear on these valves in the system just described is absolutely negligible, because the speed of the liquid in the pulsators of large section being very slow, the valves close very slowly on their seating. It should be pointed out that in the installations of this last system which the author has installed, and which have been working for more than two years, no valve has had to be replaced. This fact holds good not only in the case of small installations for garages, but also for large depots handling from 300,000 to 900,000 gallons.

(*e*) *Deterioration of Rubber Diaphragms.*—The author draws attention to the fact that the pneumatic reversing apparatus which he has described, and which in certain cases is preferable to the mechanical one of the second kind, has rubber diaphragms, as shown in the sketch, which are never in direct contact with the liquid, but on one side only with air containing a little vapour of the liquid. Under these conditions the action on the rubber of the traces of vapour of the liquid is very slow, and much less rapid than the wear which results from successive deformation of these diaphragms at each reversal.

Experience has shown that the life of one of these diaphragms (which costs about 2/-) varies from 15 to 18 months.

(*f*) *Risks of Explosion in the Storage Tanks.*—Replying to an observation by Mr. David Bywater, the risk or danger which may result from having a layer of air on the surface of the liquid in the tanks, when these are placed below ground level, is not serious, because the tanks are kept in the best condition of preservation and guarded against being tampered with. This inconvenience is much more serious in the empty tanks which are used for the transport of petrol, and which are filled by saturated vapours. It is useful on this point to insist again on this fact that in the system of pneumatic handling described, the pressure which exists in the tanks is always exactly equal to atmospheric pressure, and that during operations of stocktaking or deliveries, no inflammable vapour can escape into the atmosphere. In conclusion, the apparatus has all the advantage of being generally applicable, whatever the nature of the liquid to be handled may be, whilst with the system pointed out by Mr. Bywater, it is impossible to handle liquids which absorb water in any quantity. For instance, in France a recent law has prescribed the addition of a certain proportion of alcohol to petrol. This has at once rendered completely useless any apparatus utilising water for the handling of petrol.

THE SOCIETY OF ENGINEERS (INCORPORATED).

INCOME AND EXPENDITURE ACCOUNT, FOR THE YEAR ENDED 31ST DECEMBER, 1922.

Year ending *31st Dec., 1921.* £ s. d.	EXPENDITURE.	£ s. d.	£ s. d.
310 8 1	To Printing Transactions (after deducting Contribution by Dr. C. V. Drysdale, £10) ...	282 8 3	
48 10 11	*Less* Sales and Advertisements	41 17 8	
£261 17 2			240 10 7
	,, *Administration Expenses*—		
350 0 0	Salary of Secretary	400 0 0	
	,, ,, ,, (Balance 1921)	50 0 0	
102 0 0	Rent of Offices	102 0 0	
	Rates...	20 11 6	
22 6 1	Fuel, Lighting and Office Cleaning	34 5 1	
92 17 8	Postages, Telegrams and General Expenses ...	88 16 3	
104 4 3	Stationery and General Printing	75 14 5	
22 6 0	Audit Fee and Law Charges	25 18 11	
£693 14 0			797 6 2
	,, *Meeting Expenses*—		
7 7 0	Hire of Rooms	11 19 6	
1 1 0	Hire of Lanterns	2 12 6	
14 3 7	Refreshments for Members...	15 13 5	
£22 11 7			30 5 5
0 18 0	,, Income Tax on Bank Interest		1 1 0
3 3 1			
1 14 8			
8 8 0	,, Cost of President's Gold Meda		5 15 0
154 11 6	,, Balance, being Excess of Income over Expenditure, carried to Accumulated Fund		39 14 8
£1,146 18 0			£1,114 12 10

Year ending *31st Dec., 1921.* £ s. d.	INCOME.	£ s. d.	£ s d.
	By Subscriptions	1,022 2 5	
	Less Paid to Associated Societies	3 9 4	
999 10 11			1,018 13 1
117 1 6	,, Admission Fees		70 7 0
5 5 0	,, Donations		11 1 0
2 6 7	,, Interest on Bank Deposit ...		1 16 6
20 1 6	,, Interest on Investments, India 3½% Stock ...		7 12 3
2 12 6	,, Sundry Receipts		5 3 0
£1,146 18 0			£1,114 12 10

THE SOCIETY OF ENGINEERS (INCORPORATED).

BALANCE SHEET, 31st December, 1922.

Year ending 31st Dec., 1921. £ s. d.	Liabilities.	£ s. d.	£ s. d.
152 13 3	*Sundry Creditors*		223 12 8
46 5 0	*Subscriptions in Advance* ...		49 6 6
	Life Membership Account—		
86 2 2	As per last Balance Sheet...	81 16 0	
4 6 2	*Less* 5 per cent. transferred to Income on account of Life Subscription expired ...	4 1 5	
£81 16 0			77 14 7
	Accumulated Fund Account—		
196 19 6	being Excess of Assets over Liabilities. As per last Balance Sheet	403 11 0	
154 11 6	*Add* Balance from Income and Expenditure Account ...	39 14 8	
52 0 0	Balance of Reserve for Depreciation of Securities, the Securities having been revalued as at 31st Dec., 1922	45 11 11	
82 0 9		488 17 7	
	Deduct Value at 31st Dec., 1922, of £606 London & North Western Railway 3 per cent. Debenture Stock transferred to the Society's Premium Fund	375 14 5	
			113 3 2
£766 6 0			£463 16 11

Year ending *31st Dec., 1921.* £ s. d.	Assets.	£ s. d.	£ s. d.
	Cash—		
94 2 3	At Bank, Current Account...	72 16 9	
59 9 8	Do. Deposit Account...	127 1 2	
9 16 10	In hand	6 7 1	
£163 8 9			206 5 0
	Sundry Debtors—		
24 13 6 2 15 0 5 5 0	Subscriptions in arrear and received up to 5th February, 1923...		24 17 3
£32 13 6			
	Investments—		
524 19 0 278 13 6	£300 India 3½ per cent. Bonds at 62½ being market value at 31st December, 1922 ...		187 10 0
£803 12 6			
286 0 0			
£517 12 6			
	Office Furniture—		
16 5 6	As per last Balance Sheet...	14 2 0	
2 3 6	*Add* Furniture bought ...	1 12 6	
£14 2 0			15 14 6
	Library—		
15 12 0	As per last Balance Sheet...		15 12 0
	Stocks on hand—		
22 0 0	Transactions and Journals...	13 4 9	
0 17 3	Law Relating to Engineering	0 13 5	
£22 17 3			13 18 2
£766 6 0			£463 16 11

THE BESSEMER PRIZE FUND.

Year ending *31st Dec., 1921.* £ s. d.		£ s. d.	£ s. d.	Year ending *31st Dec., 1921.* £ s. d.		£ s. d
96 5 7	As per last Balance Sheet ...	111 5 3		101 15 0	£185 North Eastern Railway 3 per cent. Debenture Stock at 61, being market value at 31st Dec., 1922	112 17 0
11 2 0	*Add* Appreciation in value of Investment	11 2 0		9 10 3	Cash in hand	16 12 11
£107 7 7						
3 17 8	,, Income from North Eastern Railway Debenture Stock	3 19 1				
£111 5 3	,, Income Tax recovered 1915 to 1921	8 8 7				
		134 14 11				
	Deduct Cost of Premium ...	5 5 0				
£111 5 3			£129 9 11	£111 5 3		£129 9 11

THE NURSEY PRIZE FUND.

£ s. d.		£ s. d.	£ s. d.	£ s. d.		£ s. d.
31 9 6	As per last Balance Sheet ...	29 12 0		27 7 10	£33 Hammersmith & City Railway Consolidated Ordinary Stock at 108, being market value at 31st Dec., 1922	35 12 9
	Add Appreciation in value of Investment	8 4 11		2 4 2	Cash in hand	6 9 11
1 5 6	,, Income from Hammersmith & City Railway Consolidated Ordinary Stock	1 5 11				
£32 15 0	Income Tax recovered 1915 to 1921	2 19 10				
		£42 2 8				
3 3 0	*Deduct* Cost of Premium ...	—				
£29 12 0			£42 2 8	£29 12 0		£42 2 8

THE BERNAY PRIZE FUND.

£ s. d.		£ s. d.	£ s. d.
17 9 6	As per last Balance Sheet ...	18 2 5	
	Add Appreciation in value of Investment	2 19 10	
0 12 11	,, Income from North & South Western Junction Railway Stock	0 13 2	
	,, Income Tax recovered 1915 to 1921	1 10 6	
		23 5 11	
	Deduct Cost of Premium ...	—	
£18 2 5			£23 5 11

£ s. d.		£ s. d.	£ s. d.
14 11 2	£13 North & South Western Junction Railway Stock at 135, being market value at 31st Dec., 1922		17 11 0
2 3 9	Cash in hand—On Capital Account ...	2 3 9	
1 7 6	On Income Account ...	3 11 2	
£3 11 3			5 14 11
£18 2 5			£23 5 11

THE SOCIETY'S PREMIUM FUND.

	£ s. d.	£ s. d.
Amount transferred from the Society's General Funds by Declaration of Trust, being value at 31st December, 1922, of £606 London and North Western Railway 3 per cent. Debenture Stock	375 14 5	
Add Income received	12 19 0	
		£388 13 5

	£ s. d.
£606 London & North Western Railway 3 per cent. Debenture Stock at 62, being market value at 31st Dec., 1922	375 14 5
Cash in hand...	12 19 0
	£388 13 5

We have prepared the above Balance Sheet and Income and Expenditure Account from the Books and Vouchers of the Society and have obtained all the information and explanations we have required. In our opinion the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Society's affairs according to the best of our information and the explanations given us, and as shown by the Books of the Society.

3, Raymond Buildings,

Gray's Inn, London, W.C. 1.
12th February, 1923.

BEGBIE, ROBINSON, COX, & KNIGHT,
Chartered Accountants.

SUMMER VISITS.

MESSRS. BRYANT & MAY, LTD., FAIRFIELD WORKS, FAIRFIELD ROAD, BOW, E. 3, ON WEDNESDAY, JUNE 20, 1923, AT 2.30 P.M.

On the occasion of the above visit it was discovered how interesting a place a match factory can be. Messrs. Bryant & May perform the whole of their work by machinery, and in this connection some wonderful machines were seen. First a visit was paid to the power house, then the shops where the wooden and cardboard match boxes were made. Messrs. Bryant & May print the whole of their labels for the match boxes, and have many labour-saving devices for the making of the large wooden cases for packing the matches before despatch. The match-making itself is a most interesting process, especially the machinery for packing the finished article into boxes, which boxes are then wrapped into dozens and sealed.

At the close of the visit Mr. T. J. Gueritte (Past President) thanked Messrs. Bryant & May for allowing the members the pleasure of visiting their works.

VISIT TO WORKS OF MESSRS. J. LYONS & CO., LTD., GREENFORD, MIDDLESEX, ON WEDNESDAY, JULY 11, 1923, AT 2.40 p.m.

The visit to Messrs. Lyons' works was of great interest. The party was able to witness the manufacture of cocoa, chocolates, confectionery and custard powder, besides seeing tea and coffee prepared for market. The works are new and of an extensive character, the whole of the shops are well lighted and ventilated, and some of the machinery employed is almost human! Being on the canal, Messrs. Lyons are able to get large quantities of tea and other commodities right up to their doors. Greenford is "all electrical," and the fuel employed is oil.

The packing of tea is accomplished by 72 wonderful machines, the gigantic hoppers of which ascend to the roof. Descending through these by gravity, the tea, untouched by hand, is swiftly persuaded into packets, which are automatically delivered. The tea-packing machine not only weighs the tea, makes the packets to contain it, and fills, closes and labels the packets, but thoughtfully examines its own packets to make sure that they *are* filled. If tea should miss a packet or it should not be properly filled, it is thrown out !

The unloading of barges is done by an overhead electric travelling crane, and a 50 ton barge unloaded in this way takes three men three hours to accomplish.

The only regret was that longer time was not possible to be spent in examining the various departments. Messrs. Lyons thoughtfully provided tea at the close of the visit, which was much appreciated on so hot an afternoon as it proved to be, and afterwards Messrs. E. F. Spurrell and A. S. E. Ackermann complimented the firm on their enterprise and thanked them for the visit and their hospitality.

International Shipping, Engineering and Machinery Exhibition, Olympia, on Tuesday, September 4, 1923.

Messrs. F. W. Bridges & Sons kindly arranged a visit of the members on September 4th. Members of Council and Officers of our Society and those of the Surveyor's Institution were invited to lunch and the whole of the Members of the Society and those of the Surveyor's Institution were invited to tea. After tea, Dr. H. S. Hele-Shaw, Hon. F.S.E., Chairman Hon. Committee of Experts, welcomed all the visitors to the Exhibition, remarking that those present were the first of the Societies to visit the Exhibition, and that they were two of the oldest, the Society of Engineers being 70 years old and the Surveyor's Institution nearly 60. Mr. A. Stewart Buckle, Vice-President, thanked Mr. Bridges on behalf of the Society for their hospitality, to which Mr. Bridges replied. The members then dispersed to view the varied and interesting exhibits.

We were sorry that Mr. Bridges should have had to refer at the tea to the fact that only half of those present had replied to his invitation, saying that they accepted it. Naturally it makes it very difficult for arrangements to be made, especially where refreshments have to be supplied, unless those making the arrangements know how many to expect beforehand.

THE PHYSICAL PROPERTIES OF CLAY

(Fifth Paper). AND

THE DYNAMICS OF PILE-DRIVING.

By A. S. E. Ackermann, B.Sc. (Engineering).

Delayed Discussion (see pp. 25-70, Journal No. 1, 1923, Vol. XIV.).

Mr. E. J. Flight, A.S.E., wrote saying that he had thought it would be useful if the author's method of calculating the total resistance R of the soil, by means of the data supplied by his pile-set gauge, could be reduced to a formula. He had done this in the manner shown below, but now that it had been done, the formula being so uninviting, he thought most engineers would probably prefer to work out each case in detail in the manner done in the paper rather than use the formula. In spite of this he considered it was worth putting on record.

The symbols used have the same meanings as those in the paper.

Combining the author's equations (3) and (4) of p. 28, we have

$$F = \frac{M(\lambda + s)}{6gt^2} \quad \text{.......................................}(21)$$

At p. 29 it was shown that $F_m = 2F - \frac{W}{2}$ and equation (5) was $R'' = R' - F_m$

$$= R' - 2F + \frac{W}{2} \quad \text{....................................}(22)$$

From equation (8) $\lambda_p = \frac{R''l}{EA}$

$$\therefore \quad \lambda_c = \lambda - \lambda_p = \lambda - \frac{R''l}{EA} \quad \text{........................}(23)$$

$\therefore$ The work done due to the inertia of the pile was from equation (3)

$$F(\tfrac{1}{2}\lambda_p + \lambda_c + s) = F\left(\lambda + s - \frac{R''l}{2EA}\right) \text{ in.-tons}$$

and the whole work done represented by the diagram at p. 27 was

$$R\left(\frac{\lambda}{2} + s\right) = WH - F\left(\lambda + s - \frac{R''l}{2EA}\right) \text{in.-tons} \text{.........}(24)$$

$$\therefore \quad R = \frac{2}{\lambda + 2s}\left\{WH - F\left(\lambda + s - \frac{R''l}{2EA}\right)\right\} \text{tons} \text{ ....}(25)$$

Substituting the values of F and R'' given by equations (21) and (22) respectively, we have

$$R = \frac{2}{\lambda + 2s}\left[WH - \frac{M(\lambda + s)}{6gt^2}\left\{\lambda + s - \frac{l}{2EA}\left(R' - 2F + \frac{W}{2}\right)\right\}\right](26)$$

$$= \frac{2}{\lambda + 2s}\left[WH - \frac{M(\lambda+s)}{6gt^2}\left\{\lambda+s - \frac{l}{2EA}\left(\frac{2WH}{\lambda+2s} - \frac{2M(\lambda+s)}{6gt^2} + \frac{W}{2}\right)\right\}\right]$$

$$= \frac{2}{\lambda + 2s}\left[WH - \frac{M(\lambda + s)}{6gt^2}\left\{\lambda+s - \frac{lWH}{EA(\lambda + 2s)} + \frac{Ml(\lambda+s)}{6EAgt^2} - \frac{Wl}{4EA}\right\}\right]$$

$$= \frac{2}{\lambda+2s}\left[WH - \frac{Ml(\lambda+s)^2}{6EAgt^2}\left\{\frac{EA}{l} - \frac{WH}{(\lambda+s)(\lambda+2s)} + \frac{M}{6gt^2} - \frac{W}{4(\lambda+s)}\right\}\right] \text{tons.}$$

Mr. Hal Gutteridge, A.M.I.Mech. E., M.I.E.I., wrote as follows: The author has demonstrated that with London clay, when a certain differential pressure is applied, dependent on the percentage of water it contains, the material acts as a fluid. This has a useful and direct bearing on the design of retaining walls in that it gives the maximum limit of horizontal pressure a wall will have to withstand. The author has carried out his experiments with clay in a container, open at the top, with the pressure applied vertically downwards. The clay having been restrained from moving in any direction except upwards, the conditions represented those in practice, where, instead of the confining walls resisting the movement of the clay, it would be resisted by the surrounding clay. If, therefore, the container be turned on to one of its vertical sides, and the pressure act in a horizontal direction, the clay will be free to move in only one direction, i.e., horizontally outwards, and the conditions nearly represent those found in practice where material has to be restrained from moving in a horizontal direction, as in the case of a retaining wall.

The "pressure of fluidity" has been defined by the author as that pressure which, when applied to a disc resting on the clay, causes it to penetrate indefinitely into the clay without further increase of load. This usually takes place when the depth of penetration is about 1·5 times the diameter of the disc. This passive resistance of the material, the measure of which can be ascertained in practice by testing the clay in situ, would be the maximum limit of active pressure the wall would have to withstand, for, if this limit were exceeded, the clay would act as a fluid, and flow would take place in directions approximately tangential to the wall.

In practice, if we take the limiting case where a retaining wall is necessary, as in the case of clay that will just not maintain its shape without support, depending on the vertical height and the quantity of water mixed with the clay, then with any greater percentage of water the clay will exert a less pressure on the wall. When the percentage of water is about 40 the mixture has the consistency of thick cream, and weighs about 98 lb. per c. ft. (*vide* p. 104 of the first paper on the subject by the author, dated March 10, 1919). Consequently the pressure then on the wall would not be greater than that due to the static head of the mixture. With any greater percentage of water the pressure would be less until, when the limit of 100% of water was reached, the pressure on the wall would be little more than the hydrostatic head.

Dr. Herbert Chatley, D.Sc. (Engineering) wrote to congratulate Mr. Ackermann on having carried his research another stage forward.

A propos of the pile-driving conclusion as to the fraction of energy available for penetration, in 1910 he made some small-scale experiments on pile driving in sand, and then found that about half the potential energy was dissipated in elastic vibration.

The relation of the pressure of fluidity to the Brinell number is most interesting. The hypothesis of shearing and tension between spheres in contact is of course questionable from the point of view of whether there really is an equivalence between an actual structure or irregular particles and an ideal one of equal spheres. There is, however, no reason to doubt that when the particles are *very small* in relation to the area of pressure some such equivalence may occur.

In the matter of the shearing angle $\mu \doteqdot \frac{9 \cdot 47}{\sqrt{p_n}}$ for clay containing 25 per cent. of water, it should be pointed out that Ackermann's 1920 results agree almost equally well with a form—

$$\mu = \frac{43}{p} + 0 \cdot 45$$

and the 1921 results (29·5 per cent. moisture) with a form—

$$\mu = \frac{30}{p} + 0 \cdot 30$$

which conform to Résal's fundamental postulate that the tangent of the friction angle = the true friction tangent + (cohesion/pressure).

Résals expression for weak earth may be written—

$\mu = \frac{180}{p} + 0 \cdot 167$, but it may be presumed that the constants differ with material and moisture.

It would be of great practical value if all the properties (tenacity, shear, viscosity, pressure of fluidity, plasticity, etc.) could be expressed as functions of—

(*a*) The equivalent mean spherical grain diameter.

(*b*) The moisture content.

Possibly a third factor relating to the *variation* of the grain size might be necessary.

As to the moisture content, from a geometrical point of view, the volume fraction should be a better criterion than the weight fraction. A discontinuity must be expected when the interstices are no longer full.

Some rough calculations made on the basis of all available data (including Ackermann's) seem to show that—

(*a*) Viscosity varies inversely as the fourteenth power of the water content.

(*b*) Hardness varies inversely as the fifth power of the water content.

It also appears probable that the tenacity and tangential cohesion under small or zero pressures varies inversely as some power (perhaps the fourth) of the mean interstitial distance between the grain surface.

On the matter of viscosity, Ackermann's extrusion experiments in his third paper provide a partial control of his value if we assume an imaginary tube from the orifice up to the surface of the heaped clay in the closed vessel. A rough calculation gives a value of *more than* 2×10^5 c.g.s. units.

The chemical nature of the material comes into the question in some cases. In Ackermann's 1920 paper he notices the fluidity of a chalk paste with low water content, and pamphlet No. 2 of the British Portland Cement Research Association, p. 14, indicates that a *chalk* slurry with $43\frac{1}{2}$ per cent. by weight of water is as fluid as a clay slurry with 67 per cent.

The viscosity values given for metals in paper V. are higher than those obtained by Japanese investigators in recent years (see *Phil. Mag.*, 1921).

THE IMPACT OF IMPERFECTLY - ELASTIC BODIES, WITH PARTICULAR REFERENCE TO THE EFFECT OF THE HAMMER BLOW IN PILE - DRIVING.

By A. Hiley, M.I.N.A., A.M. Inst. C.E.

[Foreword.]

In making an analysis of the " Efficiency of the hammer blow " which was published in the June issues of *Engineering* in 1922, the writer made use of certain principles and formulæ concerning which several engineers interested in the subject have at various times suggested that a detailed treatment of the basic principles would provide a useful supplement to the articles in question.

Accordingly, when dealing with the problem as touched on by Mr. Ackermann's experiments with pile-set gauges, it was mutually decided that it might be of assistance to our conceptions on the problem if the present article were made available for reference by publication in the transactions of the Society of Engineers to accompany the printed discussions appearing therein on the same subject. For the present purpose the writer has restricted the article to a consideration of the theoretical principles without entering into the details of practical tests and instances of pile driving which have shown a general agreement with the formulæ and curves.

The writer has followed the notation used in his formulæ printed in *Engineering*, with the exception that the co-efficient of restitution is now expressed by *e* and the measured temporary compression set by *c*.

. . . .

Elasticity may be regarded as that property of a body by virtue of which force is required to change its form or volume, and which enables the body to recover its original form or volume when the force is removed.

In the case of pile driving the bodies constituting the hammer and pile will be treated as being imperfectly elastic in view of the fact that for such materials as iron, wood and concrete, whilst the bodies in contact after collision tend to recover their original form after having been compressed by the force of impact, they succeed in only partially effecting such recovery by the time the blow has been expended.

When the hammer strikes the head of a pile, two impulsive forces are instantaneously called into action, and are so named because they produce their effects in an exceedingly short interval of time. These forces act in opposite directions on the two bodies and cause their velocities to approach the same value. During the first period which lasts until the velocities have become equal the forces referred to are called the impulsive forces of compression.

Whilst these forces are acting, the parts of the bodies in contact become compressed until their mass centres reach their nearest distance to each other, and this state defines the duration of the period of compression or first period.

During the second period other impulsive forces act on each body in the same direction as before but differ in magnitude from the impulsive forces of compression, and whilst they act the parts of the bodies previously strained recover from their state of compression. This period is therefore referred to as the period of restitution, and the forces then exerted are called the impulsive forces of restitution.

From Newton's "Third Law of Motion," it follows that with regard to an impulsive force exerted at any time on one body there must be an equal and opposite impulse exerted at the same time on the other body.

It is also found by experiment that the ratio of the impulsive force of restitution to the impulsive force of compression has a constant value for any given pair of substances. This ratio is called the coefficient of restitution and is denoted by e.

For perfectly elastic bodies, which implies that they could recover their original form completely after being subjected to local intense compressive strain, the value of e would be unity.

For imperfectly elastic bodies, which embraces all those actually dealt with in practice, the value of e is less than 1, and for inelastic bodies which retain such deformations as are caused by the action of the external forces for the periods considered, the value of e is zero.

The experimentally determined values of e for several pairs of substances including those representative of the hammer and pile for our study of pile driving are as follows :—

Ivory on Ivory ...	0·94	Steel on steel	0·6 to 0·5
Cork on Cork ...	0·65	Cast Iron on Concrete...	0·4
Iron on Lead ...	0·15	Cast Iron on Wood ...	0·25

Taking the principle as proved experimentally by Newton that the relative velocity after impact = — e multiplied by the relative velocity before impact, it may be recalled that for his purpose Newton suspended two spheres side by side by vertical threads. On lifting up one of such spheres along the arc of a circle to a height h feet above its original position, and then allowing it to fall under the influence of gravity, the velocity v with which it strikes the other sphere is $\sqrt{2gh}$. The two spheres would then move along their arcs of circles so as to reach ascertained heights h_1 and h_2 as measured, and the initial velocities with which they commenced the ascent are $\sqrt{2gh_1}$ and $\sqrt{2gh_2}$ or v_1 and v_2. The result of experiments with the same two spheres always indicated that $\sqrt{2gh} = -e(\sqrt{2gh_1} - \sqrt{2gh_2})$ or $v = -e(v_1 - v_2)$ which thus afforded the data to enable the value of e to be determined for any given materials composing the spheres. The values of e can also be found by measuring the height of rebound, which reveals the value of v' for the case where a small sphere is allowed to fall on to a body of relatively great mass, so that it follows from this consideration that we can conveniently make use of the values of e thus derived from such experiments and apply them to our pile-driving calculations, instead of having to conduct full size experiments involving the measurement of rebound, if any, of a hammer employed in driving a pile, because the value of e simply concerns the physical properties of the materials composing the hammer and pile in their relationship to the phenomena of impact, which for practical cases is not materially influenced by considerations of strength or form.

Analysis of direct impact for the case of an iron hammer on the driving cap of a pile :—

Let W = weight of hammer.
P = weight of pile.
g = 32·2 ft. per sec^2.
e = coefficient of restitution.
I_t = Impulse causing compression.
eI_t = Impulse causing restitution.
v = velocity of the hammer at instant of impact due to a free fall h.
v_1 = velocity of the hammer and pile at the end of the 1st or compression period.
v_w = velocity of the hammer at end of period of restitution.
v_p = velocity of the pile at end of period of restitution.

At the instant of impact, the hammer has a momentum of $\frac{W}{g}v$. At the end of 1st period, being the period of compression, the momentum of the hammer becomes $\left(\frac{W}{g}v - I_t\right)$, and the velocity $v_1 = \dfrac{\frac{W}{g}v - I_t}{\frac{W}{g}}$, and momentum of the pile, assuming it free to move, becomes I_t and the velocity $v_1 = \dfrac{I_t}{\frac{P}{g}}$

The velocities v_1 being equal at the end of the 1st period

$$\frac{I_t}{\frac{P}{g}} + \frac{I_t}{\frac{W}{g}} = v = \frac{I_t\left(\frac{W}{g} + \frac{P}{g}\right)}{\frac{P}{g} \cdot \frac{W}{g}}\text{; or } I_t = \frac{P}{W + P} \cdot \frac{W}{g} \cdot v$$

At the end of the 2nd period, being the period of restitution, the momentum of the hammer $= \dfrac{W}{g} \cdot v - I_t - eI_t = \dfrac{W}{g} \cdot v_w$

$$\therefore v_w = v - \frac{I_t\,(1 + e)}{\frac{W}{g}}$$

$$\therefore v_w = v - \frac{P}{W+P} \cdot v\,(1+e) = \frac{Wv + Pv - Pv - ePv}{W + P} = \frac{W - eP}{W+P} \cdot v \ldots (1)$$

For the case where a cast-iron hammer strikes a wood cap of the pile for which the value of $e = 0 \cdot 25$, the hammer will maintain a positive velocity to the end of the 2nd period so long as eP is less than W.

If the value of eP were the greater then the hammer would rebound with a velocity $= v_w$ and the height of rebound would

$$= h_1 = \frac{v_w^2}{2g} = \frac{(W - eP)^2}{(W+P)^2} \cdot \frac{v^2}{2g} = \frac{(W - eP)^2}{(W+P)^2}\, h \ \ldots\ldots\ldots\ldots\ldots (2)$$

Again, if we suppose a pile to be driven very hard into the ground and that the weight of P is exceedingly great compared with that of W, by dividing the numerator and denominator of the last expression (2) by P^2 we find that $h_1 = e^2h$, or by dividing (1) by P we get $v_w = e\,v$ which shows, as previously stated, that the relative velocity of two bodies after impact is e times the relative velocity before impact, and for a hammer and pile

$$e = \frac{v_w}{v} = \sqrt{\frac{h_1}{h}} \text{ as before.}$$

Similarly with the hammer at the end of the 2nd period, when the energy of the hammer has produced its full effect on the pile, the momentum of the pile becomes

$$I_t + eI_t = \frac{P}{g} \cdot v_P = I_t\,(1 + e)$$

$$\text{or } v_P = \frac{I_t}{\frac{P}{g}}(1+e) = \frac{W}{W+P}\cdot\frac{\frac{P}{g}}{\frac{P}{g}}\cdot v\,(1+e)$$

$$v_p = \frac{W}{W+P}\cdot(1+e)\,v \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Proceeding by an alternative line of reasoning to obtain the expressions giving the values of v_P and v_w, we may start from the hypothesis that the momentnm of two bodies after impact is equal to the momentum before impact, which for the case of a hammer striking a stationary pile is shown by

$$\frac{W}{g}v_w + \frac{P}{g}\cdot v = \frac{W}{g}\cdot v + \frac{P}{g}\cdot o \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Also we know that $v_w - v_P = -\,e\,(v - o)$ ……………………(5)

Multiplying (5) by $\frac{W}{g}$ we obtain $\frac{W}{g}\cdot v_w - \frac{W}{g}\cdot v_P = -\,e\cdot\frac{W}{g}\cdot v$ (6)

Subtracting (6) from (4), $v_P\left(\frac{W}{g}+\frac{P}{g}\right) = \frac{W}{g}\,v + e\cdot\frac{W}{g}\cdot v$

$$\therefore\ v_P = \frac{\frac{W}{g}\cdot v + e\cdot\frac{Wv}{g}}{\frac{W}{g}+\frac{P}{g}} = \frac{W}{W+P}\cdot(1+e)\,v \quad \text{as before.}$$

Similarly multiplying (5) by $\frac{P}{g}$ and adding to (4)

$$v_w = \frac{\frac{W}{g}\cdot v - e\cdot\frac{P}{g}\cdot v}{W+P} = \frac{W-eP}{W+P}\cdot v \quad \text{as before.}$$

The velocity of the hammer and pile at the end of the 2nd period, when the full effect of the hammer blow is given out, may be summarized as follows :—

	Residual Velocity.		
	For Perfectly Elastic Bodies. $e=1$.	For Imperfectly Elastic Bodies. $e=o\cdot25$ to $o\cdot5$.	For Completely Inelastic Bodies $e=o$.
Velocity of hammer $v_W=$	$\frac{W-P}{W+P}\cdot v$	$\frac{W-eP}{W+P}\cdot v$	$\frac{W}{W+P}\cdot v$
Velocity of pile $v_P=$	$\frac{2W}{W+P}\cdot v$	$\frac{W}{W+P}\cdot(1+e)\cdot v$	$\frac{W}{W+P}\cdot v$

For such cases as in good pile-driving practice, where *eP* is less than *W* and conditions prevail favourable to effective driving, it is considered that the hammer will maintain its contact with the pile, and that the sum of their energies will be available for overcoming ground resistances met with.

Then the energy available after impact will be

$$\frac{W}{2g}\, v_W^2 + \frac{P}{2g}\, v_P^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$= \frac{W}{2g}\, \frac{(W - eP)^2 v^2}{(W + P)^2} + \frac{P}{2g}\, \frac{(W + eW)^2 v^2}{(W + P)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

For the case of assumed perfectly elastic bodies where $e = 1$, the kinetic energy available after impact would be

$$\frac{W}{2g}\, \frac{(W - P)^2}{(W+P)^2}\, v^2 + \frac{P}{2g}\, \frac{(2W)^2}{(W+P)^2}\, v^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$= \frac{W}{2g}\, v^2 \frac{W^2 - 2WP + P^2 + 4PW}{(W + P)^2} = \frac{Wv^2}{2g} \cdot 1 = W.h \quad \ldots\ldots\ldots\ldots (10)$$

The full initial energy is seen to be available as there can be no loss through impact between two perfectly elastic bodies.

Taking the case of completely inelastic bodies, where $e = 0$ the kinetic energy available after impact

$$= \frac{W}{2g} \cdot \frac{W^2}{(W + P)^2} \cdot v^2 + \frac{P}{2g} \cdot \frac{W}{(W + P)^2} \cdot v^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

$$= \frac{Wv^2}{2g} \cdot \frac{W^2 + PW}{(W + P)^2} = \frac{Wv^3}{2g} \cdot \frac{W}{W + P} = W.h. \frac{W}{W + P} \quad \ldots\ldots\ldots\ldots (12)$$

and the loss due to impact

$$= W.h\left(1 - \frac{W}{W + P}\right) = W.h.\, \frac{P}{W + P} = W.h.\, \frac{1}{1 + \frac{W}{P}} \quad \ldots\ldots\ldots\ldots (13)$$

For the general case met with in pile-driving practice, the energy of the hammer and pile combined, which as stated in (8) is available after impact, $= \frac{Wv^2}{2g} \cdot \frac{(W - eP)^2}{(W + P)^2} + \frac{Pv^2}{2g} \cdot \frac{(W + eW)^2}{(W + P)^2}$

$$= \frac{Wv^2}{2g} \cdot \frac{1}{(W + P)^2} \cdot \left\{(W - eP)^2 + WP\,(1 + e)^2\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

$$= \frac{Wv^2}{2g} \cdot \frac{1}{(W + P)^2} \cdot W^2 + WP + Pe^2(W + P)$$

$$= \frac{Wv^2}{2g} \cdot \frac{W + Pe^2}{W + P} = \frac{Wv^2}{2g} \cdot \frac{W + P - P + Pe^2}{W + P}$$

$$= \frac{Wv^2}{2g}\left\{\frac{1 - P\,(1 - e)^2}{W + P}\right\}\text{..................}(15)$$

and the loss due to impact $= \dfrac{Wv^2}{2g} \cdot \dfrac{(W + P - W - Pe^2)}{W + P}$

$$= \frac{Wv^2}{2g} \cdot \frac{P(1 - e^2)}{W + P} = \frac{Wv^2}{2g} \cdot \frac{1 - e^2}{1 + \frac{W}{P}}\text{..................}(16)$$

Considering the case by way of a summary, under the condition favourable to the hammer keeping contact with the pile, for which W is greater than eP; at the end of the 2nd period of the impact, the energy possessed by the moving masses of the hammer and pile, the loss of energy in the blow, and the efficiency of hammer-blow after impact may be conveniently tabulated as follows :—

	Case of Perfectly Elastic Bodies, *i.e.* $e = 1$.	Case of Imperfectly Elastic Bodies. $e = o \cdot 25$ to $o \cdot 5$.	Case of Completely Inelastic Bodies. $e = o$.
Initial Energy of Hammer (17)	$\frac{Wv^2}{2g}$ or $W.h.$	$\frac{Wv^2}{2g}$ or $W.h.$	$\frac{Wv^2}{2g}$ or $W.h.$
Energy Available aft. Impact (18)	$\frac{Wv^2}{2g} \cdot \frac{W + P}{W + P}$	$\frac{Wv^2}{2g} \cdot \frac{W + Pe^2}{W + P}$	$\frac{Wv^2}{2g} \cdot \frac{W}{W + P}$
Loss of Energy due to Impact (19)	o	$\frac{Wv^2}{2g} \cdot \frac{P\,(1 - e^2)}{W + P}$	$\frac{Wv^2}{2g} \cdot \frac{P}{W + P}$
Efficiency of the Blow (20) η_b	1	$\frac{W + Pe^2}{W + P} = \frac{1}{1+\frac{P}{W}} + \frac{e^2}{1+\frac{W}{P}}$	$\frac{W}{W+P} = \frac{1}{1+\frac{P}{W}}$

In order to calculate the overall efficiency of the hammer-blow for the purpose of ascertaining what fraction of the initial energy will be devoted to overcoming a resistance when sinking the pile, it is necessary to take into account two further losses, beyond that due to impact (19) as expressed in the above table, which are due to :—

(*a*) Loss of energy due to straining the pile cap, and ocal stresses occurring near the surfaces in contact, as well as those arising from an imperfectly centred blow.

(*b*) Energy expended unprofitably in the elastic compression of the pile when it is transmitting the force R requisite to give out useful work in making the pile shoe penetrate the ground at its base.

Consideration of the losses caused by the elastic compression of the materials of the pile and pile-cap.—The loss due to (*a*) may be regarded as being proportional to the intensity of the local stress set up between the hammer and the pile-cap or head and to the local shortening of the materials under impact. The quantities which are involved in this connection. cannot from the nature of the case, be directly ascertained and must necessarily be the subject of some speculation. For example, it may be assumed that the force causing the loss (*a*) may be approximately obtained by dividing the initial energy of the hammer $w.h$ by the total distance through which the head of the pile moves under the influence of the blow. As the movement produced at the pile-head includes, in addition to the general settlement at the shoe, a temporary compressive strain in the length of the pile, it becomes desirable to ascertain the amount of the temporary compression (which can be verified by direct measurement), and after determining the loss due to this cause (*b*) it will be convenient to estimate the loss due to (*a*) as being a loss which bears a certain relationship to that due to (*b*) that can be more directly dealt with. In calculating the loss due to (*b*) it will be assumed that the resistance overcome by the pile in penetrating further into the ground at each blow of the hammer will be equivalent to a single force applied through the length of the pile and expended at the shoe over its projected area.

Let R = Resistance of ground to penetration of the pile shoe.

c = temporary elastic compression of the pile.

l = length of pile.

A_0 = projected area of the pile shoe.

A = Average area of section of pile material under compression.

p = stress per sq. in. on projected area A_0 of shoe to give force R.

E = Coefficient of Elasticity of material of pile.

d = density of material of pile.

The loss (*b*) $= \frac{1}{2}RC = \frac{1}{2}R^2 \frac{l}{EA} = \frac{1}{2}p^2 \frac{A_0^2 l}{EA}$ ....(21)

$$= \frac{1}{2}\frac{Alp^2}{E}\left(\frac{A_0}{A}\right)^2 = \frac{1}{2}\frac{P}{d}\cdot\frac{p^2}{E}\cdot\left(\frac{A_0}{A}\right)^2 \quad \text{....................(22)}$$

and the efficiency correction η_3 for (*b*) is obtained by dividing (22) by *WH*.

$$\therefore \quad \eta_3 = \frac{P}{W}\cdot\frac{1}{2hd}\cdot\frac{p^2}{E}\cdot\left(\frac{A_0}{A}\right)^2 \quad \text{.........................(23)}$$

With regard to the loss of energy due to (*a*), that portion taken up in the compression of the hardwood cap (where such constitutes the active part of the helmet), may be represented by an expression similar to (21).

The loss due to the pile-cap $= \frac{1}{2} R_1^2 \cdot \frac{l_1}{E_1A_1}$.................. (24)

Where R_1 = force acting on pile head ; l_1 = length of wood cap.
A_1 = Area of Wood cap ; E_1 = Coefficient of elasticity of cap.

The loss taking place in the pile-cap can be kept within moderate limits when the area A_1 and the coefficient of elasticity E_1 are as large as practicable. The force R_1 however, will be found in practice to exceed considerably the force *R* at the shoe, on account of the impact taking place at the pile-head which receives the energy from the hammer.

In addition to the energy taken up in the cap a further portion is also taken up in the material forming the upper portion of the pile which has to take the accelerative force in the manner of a stiff spring.

A further probable loss, due to the blow being imperfectly centred, also needs to be taken into account and included in the loss due to (*a*). To cover the entire loss due to cause (*a*) it is convenient to represent the loss as being for practical purposes equal to a quarter of the expression (22).

$= \frac{1}{8}\frac{P}{d}\cdot\frac{p^2}{E}\cdot\left(\frac{A_0}{A}\right)^2$ which includes the loss due to the pile-cap or helmet if fitted, and to include a similar amount to cover the loss that takes place on the upper portion of the pile receiving a force in excess of the resistance *R* occurring at the shoe.

In making this approximation the value of *P* is taken as equal to *W*, and the loss is not then influencd by the ratios of $\frac{P}{W}$

Thus for pre-cast concrete piles fitted with a helmet, the loss

$$(a) \text{ can be taken as } = \tfrac{1}{4}\frac{W}{d}\cdot\frac{p^2}{E}\cdot \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(25)$$

and the drop of efficiency will be given by dividing by Wh, from which we get the loss of efficiency due to (a)

$$\eta_1 = \frac{1}{4hd}\cdot\frac{p^2}{E}\cdot \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(26)$$

The same drop of efficiency will also apply to the case of a steel tubular pile when fitted with a driving cap.

In the case of a plain timber pile the helmet will not be present, so that the drop in efficiency will be reduced to

$$\eta_1 = \frac{1}{8hd}\cdot\frac{p^3}{E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(27)$$

and the value of p is assumed to be not less than 500 lbs. per square inch.

To obtain the overall efficiency η (which shows what fraction of the striking energy of the hammer is available for causing penetration of the pile), we can proceed by taking the efficiency of blow after impact η_b given by formula (20) and subtracting from it the drop of efficiency η_1, caused by loss (a) together with the drop of efficiency η_3 caused by loss (b).

$$\text{Thus } \eta_1 = \eta_b - \eta_1 - \eta_3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(28)$$

The value of η for timber piles, for which the value of e may be taken as $0 \cdot 25$, is given by

$$\eta = \frac{W+Pe^2}{W+P} - \frac{1}{8hd}\cdot\frac{p^2}{E} - \frac{P}{W}\cdot\frac{1}{2hd}\cdot\frac{p^3}{E} \quad \ldots\ldots\ldots\ldots\ldots(29)$$

The energy available for doing useful work will therefore be $= Wh\eta$ expressed, say, in inch-tons, if W is the weight of the hammer and h is the equivalent height of free fall expressed in inches, and η = overall efficiency.

The value of η for pre-cast concrete piles, not fitted with a helmet, for which $e = 0 \cdot 4$ is given by

$$\eta = \frac{W+Pe^2}{W+P} - \frac{1}{8hd}\cdot\frac{p^2}{E} - \frac{P}{W}\cdot\frac{1}{2hd}\cdot\frac{p^2}{E} \ldots\ldots\ldots\ldots\ldots(30)$$

and for pre-cast piles fitted with a helmet and dolly for which case $e = 0 \cdot 25$, the value of

$$\eta \text{ becomes } = \frac{W+Pe^2}{W+P} - \frac{1}{4hd}\cdot\frac{p^2}{E} - \frac{P}{W}\cdot\frac{1}{2hd}\cdot\frac{p^2}{E} \ldots\ldots\ldots\ldots(31)$$

The value of η for a steel tubular preparatory pile fitted with a hard wood driving-cap for which $e = 0 \cdot 25$, and having a shoe of a larger diameter than the tube is

$$\eta = \frac{W + Pe^2}{W + P} - \frac{1}{4hd} \cdot \frac{p^2}{E} \cdot \left(\frac{A_0}{A}\right)^2 - \frac{P}{W} \cdot \frac{1}{2hd} \cdot \frac{p^2}{E} \cdot \left(\frac{A_0}{A}\right)^2 \quad \text{............(32)}$$

In estimating the efficiency η of the hammer blow in the case of steel sheet piles of solid section, the loss of efficiency η_3 has been calculated as $= \frac{P}{W} \cdot \frac{1}{2hd} \cdot \frac{p^2}{E}$. If a helmet containing a wood cap be employed, as may be done where a single acting steam hammer is used for the driving, the value of e may be taken as $0 \cdot 25$. For general cases where a double-acting steam hammer is used for driving, the steel ram of the hammer is made to deliver its blow on a steel anvil-block, and in this arrangement the value of e is taken as $0 \cdot 5$ when calculating the efficiency η_b. The pressure p lbs. per sq. in. is taken as acting over the cross section of the sheet pile but the value of p in the case of sheet piling requires to be augmented from 3 to 4 times that due to the ground resistance, because of the additional friction encountered in the interlocking parts, the occurrence of lateral deflections when driving, and a virtual enlargement of the end which in many cases passes into hard stony ground.

The value of η for steel sheet piles, using the augmented value for p, becomes

$$\eta = \frac{W + Pe^2}{W+P} - \frac{P}{W} \cdot \frac{1}{2hd} \cdot \frac{p^2}{E} \quad \text{..........................(33)}$$

We can now make some general observations on the application of the formulæ (29) to (33) when dealing with the different classes of piles.

Each class of pile will be identified by its characteristic values of d, E, e, and for any suitable type of hammer employed for driving, the value corresponding to the potential energy Wh will be known, and from these particulars the curves of efficiencies can be drawn for different values of p on an abscissa of ratios of $\frac{P}{W}$ which should be the salient factor in considering all other variations of the problem.

The values of p, representing the equivalent resistance of the ground below the projected area of the pile-shoe, corresponds to what would be considered easy driving if below 500 lb. per sq. in.; 1,000 lb. per sq. in. would indicate medium driving resistance and 1,500 lb. per sq. in. or over, a hard driving resistance.

In preparing the tables of efficiencies, η, and therefrom calculating the set of the pile per blow, the quantitative values of d, E and e were made use of as given in the following table, and the values of η_3 show the portion of initial energy used up in each case by the elastic compression of the pile for the conditions selected in which $\frac{P}{W} = 1$; $h = 50$ in.; and $p = 1{,}000$ lb. per sq. in.

Material of Pile.	Weight per Cubic foot in lb.	d density in lb. per per Cub. in.	E Coefficient of Elasticity lb. per sq. in.	e Coefficient of Restitution.	Ult. Compressive strength ton sq. in.	Relative value of η_3
Pitch Pine	45	0·026	1,750,000	0·25	3	0·22
Reinforced Concrete	155	0·108	2,500,000	0·25, wood cap 0·40, plain	1·5	0·04
Steel pile tube where $\frac{A_0}{A} = 6 \cdot 7$	490	0·283	30,000,000	0·25	30	0·05
Steel sheet pile	490	0·283	30,000,000	0·25, wood cap 0·50, plain	30	0·001

Typical curves of the efficiency η calculated for the case of a single acting steam hammer of 4 ft. by 6 in. stroke, when driving pitch pine piles, are shown in Fig. 1; and the amount of permanent set s, and temporary compression c produced per blow by a 2 ton hammer having an effective fall of 50 in. when driving piles of 14 in. by 14 in. section are given by the curves of Fig. 1. Likewise curves for similar conditions applicable to the driving of pre-cast concrete piles are given in Figs. 2 and 3.

In each of these cases W = weight of the hammer having an effective fall h of 50 ins.

P = the weight of the pile, helmet, and dolly (when fitted).

The energy of the blow = $W.h$ in.-lb.

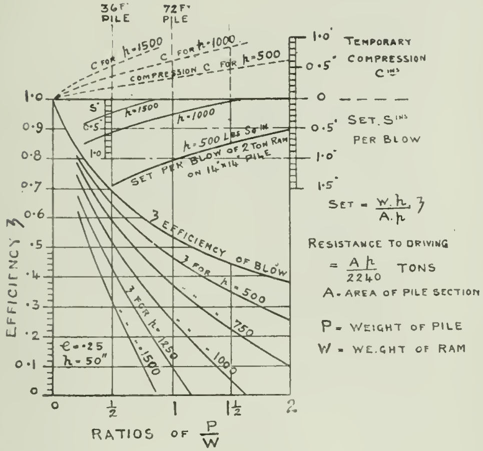
The energy of blow available for overcoming the resistance of the ground = $\eta.W.h$.

The permanent set s per blow of the hammer at full stroke = $\frac{\eta\, W.h}{A.p}$

A = Sectional Area of the pile in sq. ins. measured at one quarter its length above shoe; A_0 is taken if the shoe is the larger.

CURVES OF EFFICIENCY η OF HAMMER BLOW FOR 50" FREE FALL, DRIVING PITCH PINE PILES & SET PER BLOW OF A 2 TON RAM WHEN DRIVING 14" × 14" PITCH PINE PILES

FIG. 1.



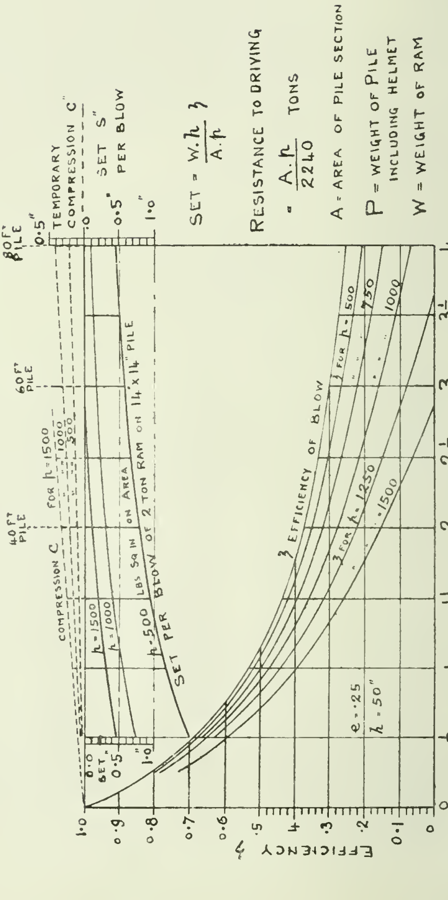
p = pressure in lb. per sq. in. on area A for overcoming the resistance of the ground which should fall within the safe strut value of timber and sheet piles.

R = Resistance to driving in tons $= \dfrac{A.p}{2240}$ or $\dfrac{A_0 p}{2240}$

It will be seen that for a given class of pile the value of η will reach a definite limit corresponding with h and p for each ratio $\dfrac{P}{W}$, so that it follows that similar piles driven against a certain pressure p by a hammer falling h'' will show the same set per blow if the ratio of $\dfrac{W}{A}$ is the same.

Thus for a definite height of fall, p and $\dfrac{P}{W}$, the set per blow measured from the curves for a 2-ton hammer driving a 14in. by 14in. pile would be identical for other ratios of $\dfrac{W}{A}$, as for instance a 1½-ton hammer on a 12in. by 12in. pile.

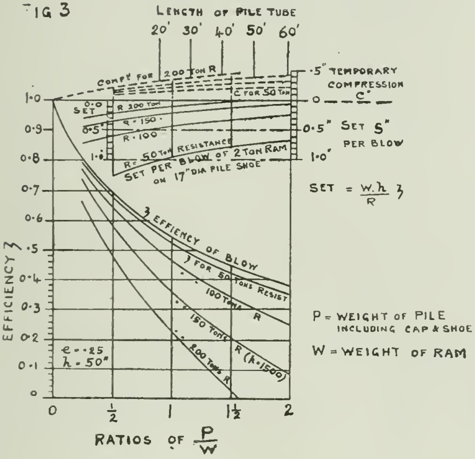
FIG. 2



CURVES OF EFFICIENCY η OF HAMMER BLOW FOR 50 INS FREE FALL DRIVING R. CONCRETE PILES & SET PER BLOW OF 2 TON RAM WHEN DRIVING 14" x 14" PRE-CAST CONCRETE PILES

CURVES OF EFFICIENCY ζ OF HAMMER BLOW FOR 50" FREE FALL DRIVING STEEL TUBE (PREPARATORY PILE TUBE 16" DIA × $\frac{3}{4}$", $\frac{A_2}{A} = 6{\cdot}7$, FITTED WITH HELMET, WOOD CAP & CONICAL SHOE) & SET PER BLOW OF 2 TON RAM WHEN DRIVING TO CAST 17"–18" DIA VIBRO-CONCRETE PILES

FIG 3



This relationship affords a convenient means of comparing different sizes of piles which are required to carry loads proportional to their cross sectional areas.

The initial energy of the hammer, whether it be of a weight falling by gravity, or of single or double acting piston type $= W\frac{v^2}{2g}$ or $W.h''$ where v = the actual striking velocity of the kinetic member of the hammer and h = the equivalent height of fall corresponding to v.

To ascertain a safe load which a pile will carry without settlement by an independent calculation for any given instance.—A fair estimate of the resistance of the ground to penetration by the pile, which has been actually overcome by the hammer, may be made by the following method without entailing reference to special charts or curves of pile driving data.

Let W = weight of the hammer expressed in tons.

h = the equivalent free fall of hammer in inches required to develop the actual velocity of impact.

P = weight of the pile in tons, plus any other mass set into motion by the hammer, such as the helmet or anvil.

e = coefficient of restitution taken as = 0·25 for iron striking on wood.

0·40 for iron striking on concrete.

0·50 for iron striking on steel.

The initial energy of hammer = $W.h$ expressed in inch-tons.

The energy available after impact of the partially elastic bodies $= W.h \cdot \dfrac{W + P.e^2}{W + P}$

This energy is used up partly by compressing the pile, and partly by doing useful work in causing penetration.

Let s = permanent set or penetration per blow in inches.

c = temporary elastic compression of pile in inches as calculated and verified by the aid of a pile-set gauge.

R = Resistance overcome in the ground in tons.

$$\text{Then } W.h \cdot \frac{W + P.e^2}{W + P} = R\left(s + \frac{c}{2}\right)$$

$$\text{or } R = \frac{W.h}{s + \dfrac{c}{2}} \cdot \frac{W + P.e^2}{W + P}$$

The safe load should not exceed in the case of timber and pre-cast piles $\dfrac{R}{3} \times \dfrac{D^2 + \dfrac{D\,l}{40}}{D^2 + \dfrac{D\,l}{20}}$ where D = diameter of pile in feet.

l = length of pile in feet.

This includes a true factor of safety of 3.

In the case of a tubular preparatory pile, fitted with a shoe having a larger diameter of rim than the pile tube, the safe load should not exceed $\frac{R}{3} \times \frac{D^2 + \frac{D\,l}{40}}{D^2}$

which also includes a factor of safety of 3.

For the purpose of estimating the resistance, in the absence of direct measurement of the temporary compression, a suitable allowance for the value of c for medium and for hard driving can be made as follows :—

Type of pile.	Temporary compression C in. per 10ft. length of pile.	
	Medium driving (p = 1,000 lb. sq. in.)	Hard driving. (p = 1,500 lb. sq. in.)
Timber pile ...	0·10 in. per 10 feet of length	0·15 in. per 10 feet length of pile.
Reinforced Concrete pile ...	0·06 in. ,, ,,	0·10 in. ,, ,, ,,
Steel tubular pile for which $\frac{A_0}{A}$ = 6·7	0·06 in. ,, ,,	0·10 in. ,, ,, ,,
Steel sheet piles ...	0·02 in ,, ,,	0·05 in. ,, ,, ,,

It is hoped that the methods of analysis explained in the foregoing will be found of assistance when comparing available data of pile-driving, and provide a suitable basis from which to proceed in making further investigations into the subject.

VISITS.

"NEVER-STOP RAILWAY."

We had the pleasure of receiving an invitation from Mr. Yorath Lewis to inspect the full scale working railway of the above title which he and Mr. Adkins invented and designed. Mr. Yorath Lewis will be known to our members as author of papers read before the Society on "Intermittency: Its Effect in limiting Electric Traction for City and Suburban Passenger Transport," p. 121 of 1912 Transactions; "'Bus *v.* Tram Controversy," p. 20 of 1913 Transactions.

The first example of this railway is erected in the grounds of the Kursaal at Southend, and is regularly carrying passengers as one of the side shows. We had previously inspected the calculations, diagrams, working drawings, etc., in connection with the development of this railway, and at that time were impressed by the great amount of brains, care and labour which had been spent in developing the system, and the ingenious methods by which the many practical difficulties had been overcome; but it was not until we saw the actual railway at work that we realised how extremely simple the details are, though we fully realised what brains and trouble the inventors and designers must have had in order to overcome the many practical difficulties in the simple manner in which they have overcome them. Briefly, the principle of the railway is that the coaches form the nuts on a screw, which screw revolves, and constantly causes the coaches to travel along; but the pitch of the screw is varied, so that at the stations it is only 1 ft., while between the stations it is 8 ft. No ordinary nut would work on a screw of this character, but this "nut" consists of two rollers on vertical axes, which embrace the thread of the screw. Only one of these rollers, usually the forward one, is in use at any one time, and only one such "nut" is fitted to each coach. The screw is built up of a steel tube 12 ins. in diameter and 34 ft. long, the metal being ½ in. thick. The screw thread is formed of a steel strip

$2\frac{3}{4}$ in. wide by $\frac{3}{4}$ in. thick, supported by 6 in. distance pieces from the 12 in. tube just described, so that the external diameter of the thread is 24 in. The 34 ft. lengths are supported at each end by bearings and by a very ingenious, though perfectly simple, method. At these ends the threads are overlapped in a direction parallel to the axis of the tube, but are separated by a gap of about 3 in. considered radially from the centre of the tube. The casting of the bearing passes between this gap. The rollers which form the nuts are made deep so as to engage with both ends of the overlapping threads. This overlapping is only a matter of about 4 in., which is ample to ensure the continuity of the effect of the thread.

Where the inclination of the track alters, the ends of the lengths of screw are connected by a form of enclosed flexible joint, which has the effect of a Hook's joint.

The curves, which immediately raise difficulties in the mind of an engineer first thinking of this problem, are negotiated not by means of a continuation of the screw, but the carriages are carried round the curves by means of a rotating arm, forked at each end and geared to the mechanism which drives the screws. As a coach comes to the end of a straight screw and is about to pass round the curve, one end of the forked rotating arm engages a pin under the coach and carries the coach round the circular curve by that means, and the carriages are so spaced that when the other end of the forked bar comes round to the same point another pin of another coach is there ready to engage with it and be carried round in the same manner.

The coaches seat eight people, and in plan are in the form of a box 10 ft. × 6 ft., with the two back corners cut off at angles of 45°, so as to enable the coaches to pass round the curve of only 3 ft. radius!

The screws are driven by bevel gears from a motor shaft, which shaft also drives a worm wheel to which is attached the rotating arm for negotiating the curves.

The speed of rotation in the screws is 80 r.p.m., which gives a speed of 2 miles an hour to the coaches in the stations and 16 miles an hour between the stations. The boarding and alighting from the coaches at the stations is even easier than in the case of the now familiar escalators on the tube railways in

London, and we think that if the speed of the coaches at the stations was increased to 3 m.p.h. there would be practically no more difficulty, and this would enable the speed between the stations with the same pitches of the screw to be 24 m.p.h. instead of 16. On this particular railway the two screws, one for the down journey and the other for the up, were 6 ft. 6 in. apart, and the two screws were together driven from each end by two 40 h.p. electric motors, the length of double track (each 3 ft. 6 in. gauge) being 150 yards, and the number of coaches 25.

Naturally, with a large number of engineers inspecting this railway it would have been strange if some of us had not some ideas for improving on the present arrangements, but these were pretty obvious improvements, and we have no doubt that the company, with the aid of the able inventor and designers, will make these in future designs. For the present, we heartily congratulate them on having brought the invention so near to perfection as they have done with the very first attempt at constructing a full-size railway, and hope that it will be adopted for the Metropolitan Railway in Paris.

Visit to British Empire Exhibition.

By kind permission of the authorities a visit was paid by members of the Society to the British Empire Exhibition in course of construction at Wembly, on Wednesday, September 19, 1923. The party was met and conducted over the site by Mr. B. Hooper's assistant, of the Publicity Department of the Exhibition, whose unfailing guidance and attention were much appreciated.

Most of the buildings were far enough advanced to permit of a thorough appreciation of the architectural and engineering skill displayed in the various designs, and the many applications of reinforced concrete were in themselves a witness to the advanced stage to which the knowledge of that particular branch of engineering has arrived. Particularly was this so in the cases of the Stadium and the Palace of Engineering. The former structure is more or less familiar. An idea of the latter may perhaps be gained from the fact that it consists of seven bays, each 75 ft. wide and 900 ft. long, the whole building being roofed with glass.

A track of standard gauge is laid along the centre of the whole length of each bay to facilitate the arrival and erection of machinery and plant. The model power station, situated in the building, is sure to be a great attraction for all engineers.

There was much still to be done, but, as a result of the visit, we feel convinced of the truly magnificent spectacle that will be displayed to the eyes of the world when the Exhibition opens next year, and we all hope it may be the means of effectively starting that revival in Empire trade we all so much desire and which has been longed for for four or five years.

Monday, October 1, 1923.

G. A. BECKS, A.M.I.C.E., VICE-PRESIDENT,
IN THE CHAIR.

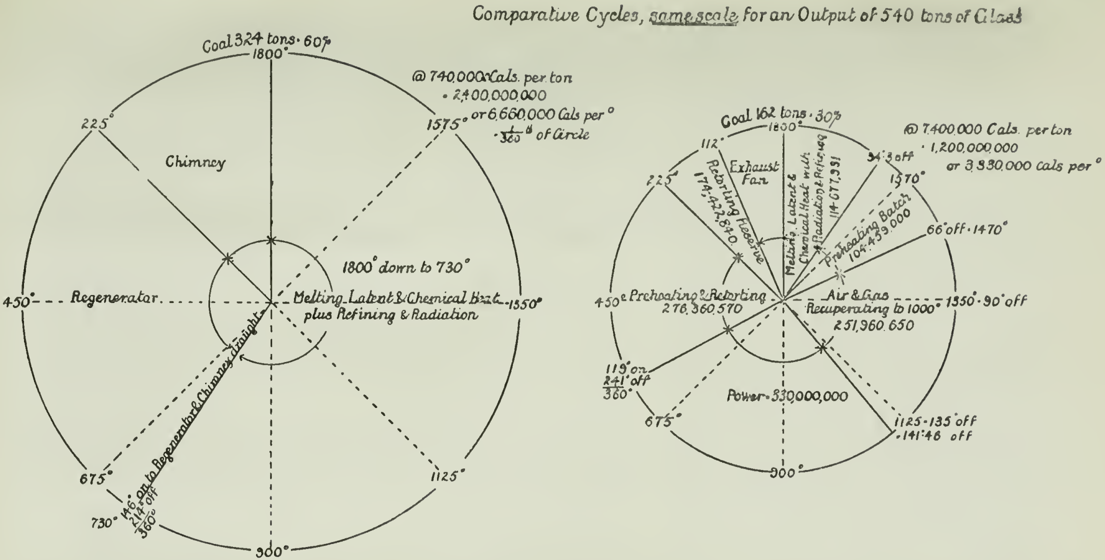
A NEW ENTIRELY AUTOMATIC MACHINE FOR MASS PRODUCTION OF GLASS BOTTLES.

By ALEXANDER FERGUSON, A.S.E.

In preparing a paper on this subject it is scarcely possible to treat the machinery without a sketch of the mass production of glass which makes it desirable to find a machine to handle the glass when made. The cyclone method allows 540 tons of glass to be made in 168 hours per week, or 120 bottles per minute. Ordinary tanks deliver from 120 to 170 tons to serve machines with a limit of 30 to 48 bottles of 16 oz. glass per minute. These tanks usually require 100 tons of coal to 100 tons of glass, and in the best practice to date a great achievement was 60 per cent. coal to glass under highly efficient technical supervision and advice.

In a paper read recently before the Society of Glass Technology, it was shown by well authenticated physical, chemical and metallurgical smelting and furnace data that it is possible to melt and refine glass using, instead of 60 per cent. coal, not more than 30 per cent., with a safety margin of $13\frac{1}{2}$ tons in each 100 tons glass, in a novel furnace occupying 600 sq. ft. instead of the present 8,800 sq. ft., and yet leaving the ground area practically clear for any other purpose. This means 1,209,600 bottles per week (1,451,520 can be turned out by an increased diameter of the wheels), three times to-day's very best, with no greater cost in labour or fuel than for the smaller output. The output can be increased for smaller bottles or reduced for larger ones, and is in strict accord with the time taken to cool the glass, while 40 to 48 varieties of like capacity can be made simultaneously. It is no use talking of mass production unless it can be got independently of skilled labour. This plant and machinery is therefore entirely automatic throughout, and no skilled labour (outside the machine repair shop) is required after the chemist or glass maker has settled the batches for the glass required.

Firstly, it must be understood that throughout this paper no fanciful hypothetical estimates are presented, but complying with your secretary's request I have kept all calculations out of the body of the paper and prepared an appendix showing in detail each constant and other details of each problem. As the numbers occur in the paper corresponding numbers in the appendix show how the answer is obtained. Everything is soundly based on well authenticated and generally accepted data, but in glass it is necessary to bear in mind that for melting, etc., no heat under 1,350° C. can be considered. Fig. 1, shows two cycles on the same scale. They demonstrate what it is necessary to get, and at what temperatures, from 90 tons coal in the cyclone and 324 in the square tank. They (A) show that though in the square tanks 2,397,600,000 calories are required, the same result, but with air and gas at 1,000° is given by the cyclone with 692,577,157 calories. These figures plainly demand a plant to enable this to be safely obtained in practice, and it is proposed to demonstrate how this may be done. Regard must be paid to (*a*) what glass is, its viscosity, devitrification and opposing skin strains, (*b*) the plant must be suitable to these peculiarities, low in construction costs, of limited ground area, of long life, requiring the minimum of attention, and permitting the whole outlay to be refunded by a negligible amortization of say 1d. per gross to cover furnace tank recuperation and lehr structures, and a further 3d. to cover machinery. (*c*) It must be durable and fool-proof throughout, (*d*) efficient against all opposition, output, labour costs and upkeep ; entirely automatic throughout and capable of continuous or intermittent action. (*e*) The moulds must be capable of being changed without stopping the machine. (*f*) Everything must be synchronized. The cooling time of each capacity of bottle must determine the speed throughout. (*g*) The whole or parts of machines must be removable for replacement by spares. (*h*) No surplus heat must be unused. (*i*) The coal must be retorted to recover volatiles and prevent smoke in the furnaces, and all batches preheated to 500°. The coal when retorted to soft coke must be broken and delivered to producer. (*k*) Producer gas must be rectified and the producer must use CO_2 from the carbonates as fuel, 23 tons as carbon and 61½ tons as oxygen to burn to CO with a further 23 tons of coke from the bed of the producer. The CO_2 brings with it 1,050° heat from the preheater to counter this endothermic reaction. (*l*) The non-condensible gases from the retort go to the gas flue to enrich the calories in the producer gas. (*m*) Burners must ensure no ungasified carbon in the flame. (*n*) The sand and lime must be again preheated as highly as possible by waste gases out of contact to drive off the CO_2 as quickly as formed, and during this last preheating the sand and lime should be thoroughly mixed in contact with the hot plate bed of the preheater and so delivered at 850° to the blade mixer and thence to the spreader revolving together at 160 to 200 r.p.m. (*o*) In the mixer the lime and silica meet the soda and its CO_2 comes



Comparative Cycles, same scale for an Output of 540 tons of Glass
Coal 324 tons · 60%
1800°
@ 740,000 Cals. per ton
· 2,400,000,000
or 6,660,000 Cals per °
· 1/360 th of Circle
225°
1575°
Chimney
1800° down to 730°
450°
Regenerator
Melting Latent & Chemical Heat plus Refining & Radiation
1350°
146° on to Regenerator & Chimney draught
214° off
360°
675°
730°
1125°
900°
Coal 162 tons · 30%
1800°
@ 7,400,000 Cals. per ton
· 1,200,000,000
or 3,330,000 Cals per °
112°
225°
Exhaust Fan
Retorting Reserve 174,422,840.
Melting Latent & Chemical Heat with Radiation & Refining 114-677,391
34·3 off
1570°
Preheating Batch 104.459.000
66° off · 1470°
450°
Preheating & Retorting 276,360,570
Air & Gas Recuperating to 1000° 251,960,650
1350° · 90° off
119° on
241° off
360°
675°
Power - 330,000,000
1125 - 135° off
· 141·46 off
900°

FIG. 1.

off and is drawn by the preheater vacuum away from the funnel (*p*) while the oxides enter the hot almost vacuum vortex of the whirling combustion products. (*q*) The surfaces (*e*) so immediately and simultaneously exposed to the heat of the furnace (Fig. 2) must present the largest area possible, the penetration be the least possible, and the etherous medium in which the reactions take place the rarest possible, while the facilities to assist speed of formation of molecules of the affinities must be the greatest attainable to make the homogeneity the most complete. (*r*) The walls of the furnace funnel must be so inclined that the molecules of glass once formed and cast forth from the whirling gases coalesce into a liquid homogeneous paste, and roll down the walls like glucose under the influence of the radiant heat, while the column contracts centripetally under the influence of reduced heat and gravitational forces. (*s*) The glass having rolled down and out of the funnel must, ever swirling, pass through the stream line tank to the forehearth. (*t*) In the forehearth the glass is gathered and delivered to the bottle forming plant.

The furnaces shown diagrammatically in Fig. 2 were first evolved in the inventor's head in trying to thrash out an economical method to provide giant telescope lenses of perfect homogeneity. The funnel of high temperature whirling gases seemed to open the way to melt high temperature materials instantly into a homogeneous whole. The idea was that the globular paste thoroughly amalgamated without stirring or any external action would fall into a temporary tank and remain there until completely annealed *in situ*, and the crude lens extracted for grinding and polishing.

The first point to be noticed in Fig. 2 is the shape of the furnace, which gives the greatest space where the gases are most rarefied and the atoms most spread out. The burners set tangentially give the whirling motion to the gases which travel about 175 ft. per second and whirl round about 7 times. The whole course of the combustion products is about 350 ft. or 2 seconds on the journey (1).* The heat of the flame is about 1,800°. (2.) The batch materials ground to pass 60 mesh means an average, with fines included, of about 1/10 mm. diameter. This presents to the heat about 6,300 times more surface for each cubic metre of batch than if the batch was filled on as in an ordinary square tank (3), and the permeation or penetration of heat is only 1/20 m.m. or one two-thousandth part of the penetration required to pierce 10 c.m. depth of "filling on" in a tank. The viscosity (4) of the semi-formed glass is 1,600,000 as great as the combustion gases, and that number

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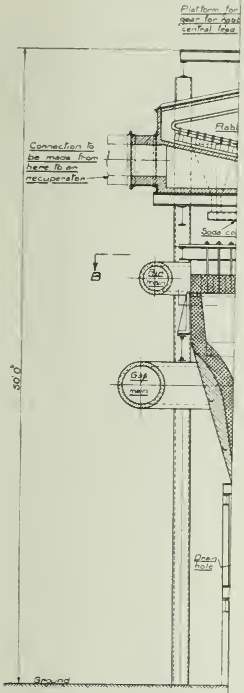
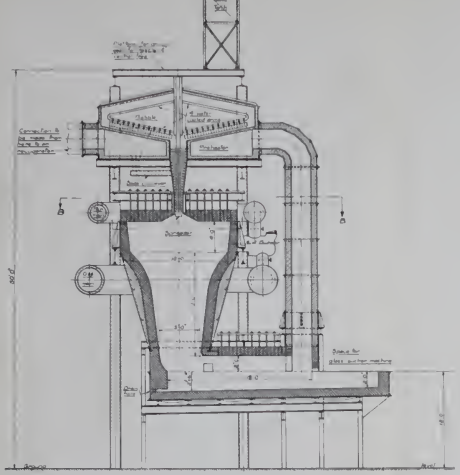
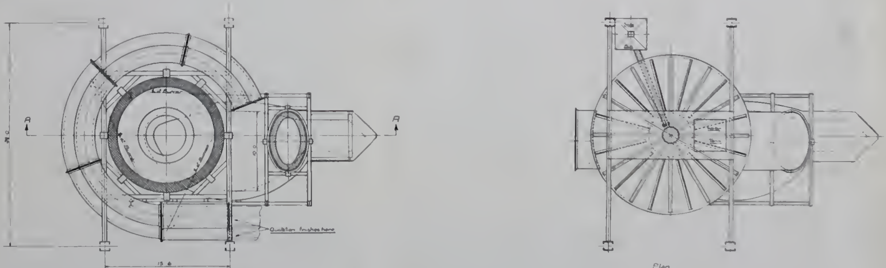
* These numbers refer to the Appendix.


Platform for
gear for rabb
central feed
Rabb
Connection to be made from here to an recuperator
Soda co
B
Air main
Gas main
50'0"
Drain hole
Ground


Connection to be made from here to an recuperator
Preheater
Oil Burner
Gas
Space for glass cutter machine
Open hole
Ground
Level
A
B
B
90'0"
18'0"
3'10"
18'0"

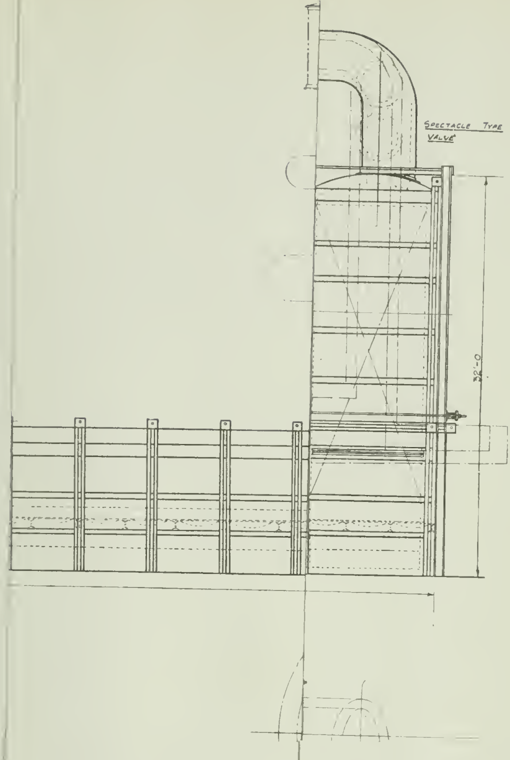
Section AA



Section BB

Plan

FIG. 2.


SPECTACLE TYPE VALVE
32'-0

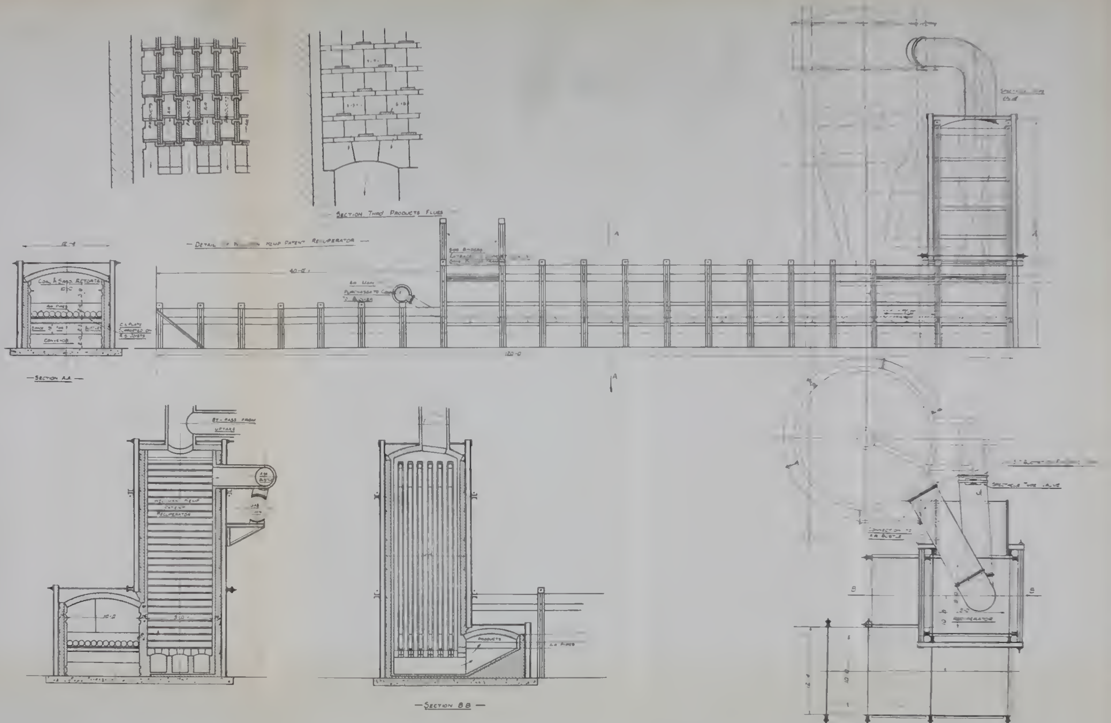

Section Thro' Products Flues
Detail of Recuperator
Coal & Sand Retorts
Section A.A.
Conveyor
By-pass from Uptake
Patent Recuperator
Products
Section B.B.
40-0
120-0
12-4
10-0
Recuperator
A
B

Fig. 3.

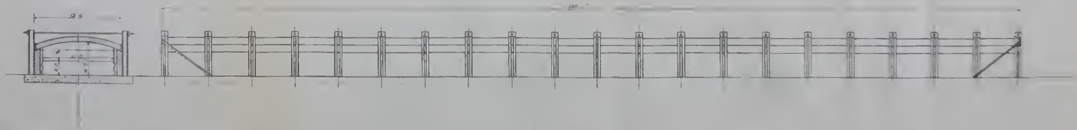

12-4
120

Fig. 4.

of times easier for affinities to react between each other, and they must reach each other before any new molecular formation can take place. Further, the batch stuff delivered from a spreader revolving 3 times in a second is spread into the almost vacuum vortex in very limited quantities at a time, and the new molecule of glass is completely formed before it passes to reach the furnace walls. When these new molecules, now larger and heavier than the gas molecules, are cast out by centrifugal force from the whirling column, they take with them the calories required to melt the batch (7), also the latent heat (8) and chemical heat (6) (if a loss) required for the formation of the molecule also the heat radiated from the furnace (10) until the melt has occurred, as well as the radiation from the whirling column which is then [(11) see Cycle] (Fig. 1) one volume less in bulk, contracts centripetally, so withdrawing it from the funnel walls. The glass paste acts as an armour plating against abrasion and soda action on the bricks, at the back of which is a heavy filling of brick dust and Kieselguhr between them and the iron casing, thereby reducing the outer surface to blood heat and the radiation loss to one-seventh of the otherwise radiation losses (12).

The suspended roof of the funnel and tank prevents outward thrust and is more lasting than an arch under constantly varying expansions and contractions. The glass is caught in a streamline tank, and passes on to the forehearth and machines while the gases go to preheat the batch. The whole of the work (13) of final preheating, driving off CO (6) melting (7), consolidating (14) the glass and all radiations is got well above 1,350°, and the combustion products pass down the recuperator, heating (16) the air for burning the CO and H to 1,000°. A recuperator is chosen because it requires no turning over every 15-20 minutes, with the accompanying nuisance of filling the furnace with smoke and unburnt particles. The author's experience with regenerators is that the combustion products seek the straightest way out, and bricks that are most vitrified (the cross baffle ones) are exactly those that catch the outgoing heat but do not present their hot side to the cold incoming air. A regenerator to be really effective must be larger with more friction surface where gases are rarefied by heat and increased in volume, and smaller where the heat is least and the volume decreased.

It is highly desirable that the batch should reach the funnel as highly preheated (13) as possible by waste heat so as to give the fresh heat as little to lose as possible—besides, heating up to 1,000° drives off all the CO_2, though it reduces in doing so the temperature to about 850°, but it is equally important to get the gas and air to the same temperature if it can be arranged. For this no better contrivance than the thin tile recuperator (Fig. 3) is known if a constant flame in one direction has to be provided. So

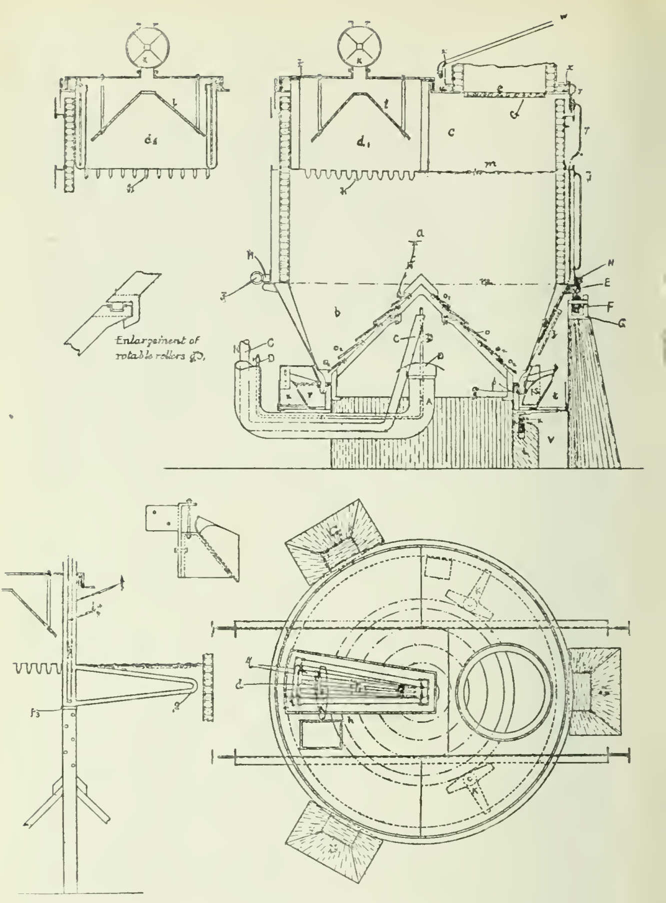
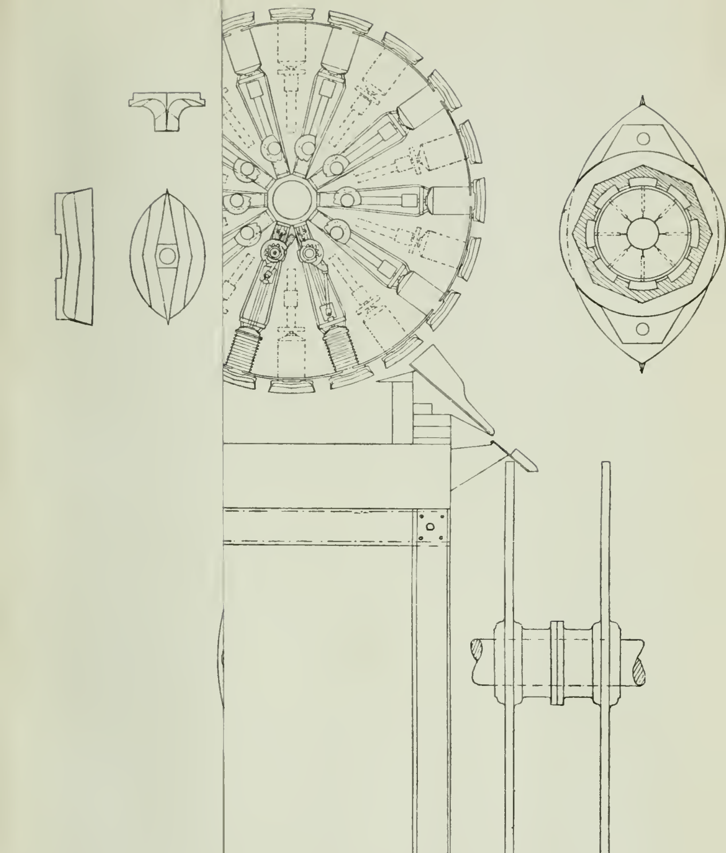


FIG. 5.

A Steam injected air pipe.
B Diffuser for same.
C CO_2 from pre-heater at or ex 1,050°.
D Emergency ampressed air pipe.
E Weight carrier.
F Roller bearings.
G Cement carrier for shaft of same.
H Worm cogs, 1 worm drive.
J Overflow from water jacket to ash pit.
K Air tight feed valve.
L Cement support for rollers.
M Fixed grate carriers.
N Rotating mushroom apex to grate.
O_2 Fixed grate of circular plates.
O_1 Rotatable circular plates.
P Ash crusher.
Q Quartz basket.
S Ashplough in water seal trough.
V Ash collector.

a Coal bed-incandescent zone at lower m block at upper m.
b Ash zone.
c Gas zone.
d Fuel feeder.
e Quartz grating and exit for gases.
f Water sealed cover to feeder.
g Rotatable rollers to movable grate apex.
h Feeder rake to level coal bed.
k Coal valve air tight.
l Coal sizing distributor.
m Coal bed limits.
o Grates for fixed crusher and rotating crusher.
q Ash delivery.
r Water seal.
s Spade.
t Outer ash box for ashes from (*r*).
u Scraper to remove ash to outlet to V.
w Water pipe.
x Water sealed top.
yy Overflows water seals to producer rotating body.
zz Overflow pipes from water-jacket to ash zone.

Small section apart for Gs upright centre support, CO_2 delivery and *g* fixed water jacketed poker and apart enlargement rotating scraper, removing all ash each revolution.



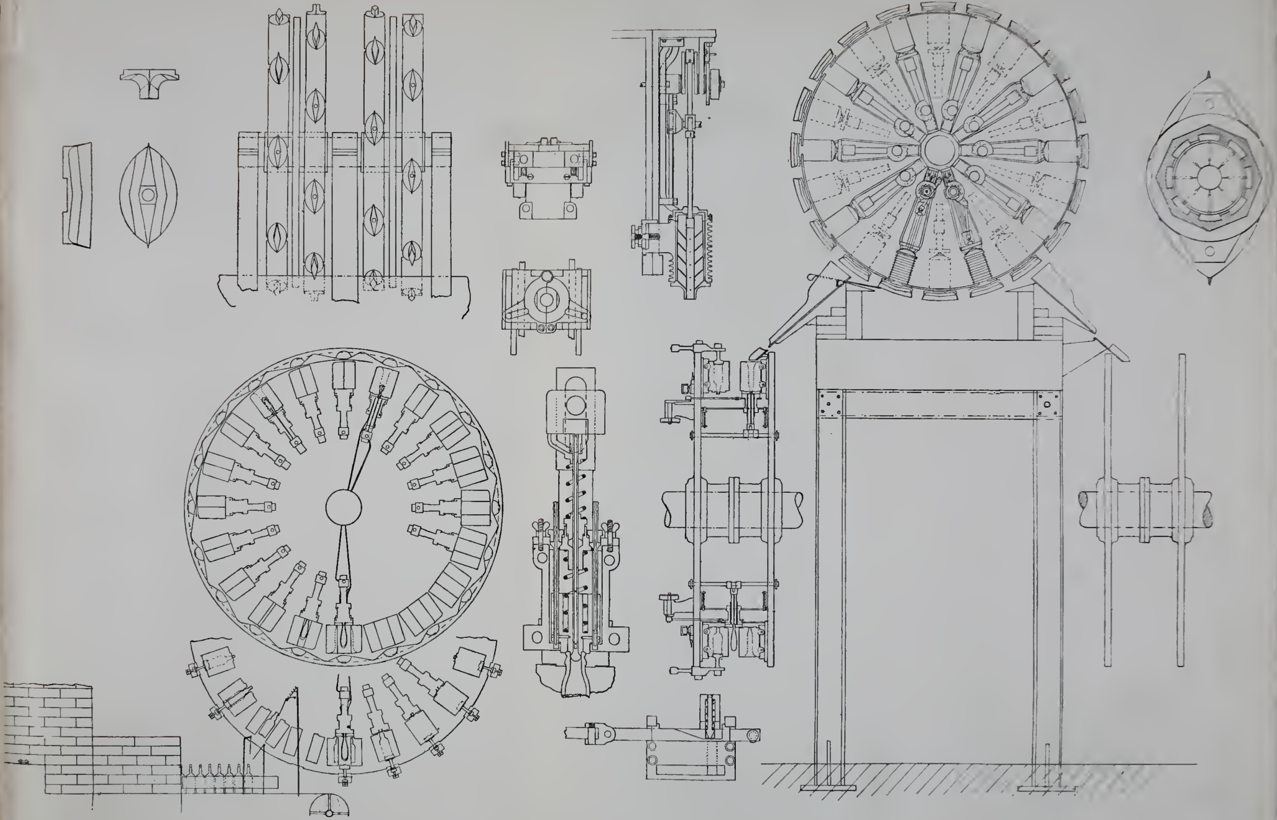


FIG. 6.

over the lehr (Figs. 3 and 4), with its 550° in waste heat and 850° (18) from glass, the air is first passed in iron pipes and then up the recuperator to the burners. The gas from the producer (Fig. 5), is at a temperature of 700° or more, and the gas conduit in the recuperator brings it up to over 800°, so batch air and gas go in at about the same temperature, and give the fresh heat little to do to raise the temperature to melting point, 1,150° plus latent heat. Having explained the glass, heat and air problems, the machines for this mass production can be dealt with :—

An 8½ ft. dia. funnel requires a machine for 270 tons per week.
12 ft. ,, ,, ,, ,, 540 ,, ,,
14 ft. ,, ,, ,, 810 ,, ,,
16 ft. ,, ,, ,, ,, 1,080 ,, ,,

The smallest is somewhat too restricted in area and the cost and upkeep nearly as much as the 12 ft., as the wider the funnel the better, if the height is always 10 per cent. more than the diameter above the cone proper ; this in the larger means two tiers of burners, one above the level of and between the others.

Fig. 6.—The gatherer depends for size and suction on the quantity to be gathered for each bottle. This means that first must be known (19) the weight of glass wanted, the weight per cubic foot of the glass (say 120 lb.), or for a 16 oz. bottle 10·8 cubic inches of glass. The length of the gatherer is 10·8 ins., so the area of the circle to give the exact contents to be gathered will be 1·11 ins. in diameter in the suction tube. The plunger gathers the exact quantity desired, a 24in. vacuum being used with positive controls, and a series of needle holes in the cylinder emerging into ducts $\frac{1}{16}$ to $\frac{1}{12}$ of an inch connected with the outer suction chamber to withdraw any possible air between the plunger and the glass, and to help to expel the molten glass on the down drive actuated by the positive mechanical cam action of the plunger aided by compressed air at 30 lb. pressure, though the compressed air is itself sufficient to expel and the suction to gather the glass. The small column of glass is in contact 1½ seconds with the sucker and ½ second in the conduit, and the total loss of temperature is about 4°-5°. (20) This loss is sufficient to reduce the heat in the glass up to the mouth of the parison to about 1,296°. When the glass enters the parison a new factor intervenes. There is now iron on one side of the glass and air pressure on the other. The parison and neck mould reduce the temperature by about 266° to 1,030°. Leaving the parison through open cool air, the glass hanging perpendicularly from the clutch blower, passes over to the shaping wheel, where it is moulded into shape, the loss in heat being about 200° ; so leaving the mould, it goes to the conveyor at about 830°, it is set, and enters a tunnel to the closed annealing chamber or lehr (Figs. 3

and 4), and passes out at N.T.P. on to another conveyor with a resilient underlay to the sorter and warehouse.

The gathering suckers are set staggered on two vertical wheels on the periphery on each side of the wheel, sucking mouth outwards. The wheels for 120 bottles a minute are 7 ft. 6 ins. in diameter and 2 ins. thick. There are two with 10 gatherers each on each side, *i.e.*, 40 in all. The wheels travels 3 r.p.m., one clockwise and the other the reverse. The staggered suckers sucking in alternate succession in four lines, keep the glass always in motion and fresh, to ensure which, as the forehearth is enclosed, a small chimney draws some of the heat of the furnace continually over the face of the glass metal. The gatherers deliver their blobs on to a conduit which is water-cooled, one on the right side of the forehearth and the other on the left. This conduit guides the blobs into the mouth of the parison or blank mould. The paramould or double parallel wheel is 8 ft. in diameter for 120 bottles per minute, and for the 144 bottle per minute the gathering wheel is 9 ft. 6 ins. instead of 7 ft. 6 ins., and the paramould wheels are similarly increased to hold 48 instead of 40 moulds. Though these wheels are large in diameter they are vertical and occupy little area of floor space, and travelling only 3 r.p.m. there is no strain on the periphery. Three revolutions per minute is fixed for 16 oz. bottles representing the time required to cool 2 + 11 + 19 secs. = 32 secs. in the moulds from intake to expulsion of the finished bottle to the lehr conveyor, including which it means 80 secs. to the lehr. The shafts of all wheels are fixed and bored for suction, air, water and gravitational lubrication. As the wheels rotate, the bore of the wheel tube box comes over the shaft openings, and, as the case may be, the suction draws in and the air expels constantly at each hole in succession in the rotation. As the gatherer rotates there is the always present hanging tag to the glass just gathered. This is detached by the 'doctor' provided with a water-cooled hoe, and falls back instantly into the hot metal. The regulating factor throughout is the time for the glass to get down to setting point. When the glass changed to liquid from solid it absorbed 100 calories per kilo in latent heat, and it is due to return it at the change from liquid to solid state. The author does not know whether this return is got on setting in the shaping mould or in the lehr, because although the glass is set at 850°, yet it is not brittle hard. If it is given back only on the glass becoming brittle hard, then there is a further 100 calories per kilo or 54,864,000 to credit the lehr for preheating, etc. Against this there is the scientific hypothesis that glass is an under-cooled liquid, in which case presumably the latent heat would not be returned nor accounted for.

To be treated by machinery entirely and have a brilliant skin the glass must be hotter than for hand working, in which there is no appreciable contact with cold iron. There are many ways of gathering, but the modern development of the old syringe still holds first place, but usually requires an open-fronted revolving saucer tank supplementary to the tank proper. The Owen's gatherer is blunt-nosed, and carries a wave of rolling glass with and in front of it, and which tends to devitrification and crystallisation of cooled liquid, as it always sucks in the same spot. The Cyclone machines occupy only 8 × 2 or 16 sq. ft. on each side of the fore-hearth, *i.e.*, 32 sq. ft. in all or one-eghth area, with three times the Owen s capacity, although the times in the moulds in both machines are identical. The staggered suckers, revolving both ways, draw the metal back and forward, no part is still. This gives new glass each suck, and as no part of the furnace is ever open to the air it keeps the metal " champion," as the glass-workers call it, and being mounted on the periphery of the wheel, it allows a bent tile to close up the spaces between the sucking mouths and keep the heat in. Further, every sucker mouth is set in a boat-shaped float with destroyer stems fore and aft, and as the passage or travel through the glass is only 26 ft. or 78 ft. per minute, one can imagine the wash of a destroyer stem going through glass of great viscosity, especially as the stern is similarly formed. So in the forehearth we are able to get constant level and still surface with constant heat on top of the glass and a no-ripple gathering. Thus the gathering of 120 to 144 bottles a minute is solved.

Remembering that these machines are continuous, please note the catchment area of the parisons directing the blob from the conduit into its own compartment and synchronizing exactly to the speed of the gatherer, the gatherer and paramould being geared together and driven by one drive. In this method the blob slides down the conduit into the catchment area as it revolves with the paramould, which travels along parallel with it, so suiting the catchment and delivery to the travel, slightly faster or slower as the blob differs in its glide from the gatherer to the parison. Into this it settles by gravity and suction, gravity by the weight of glass at the neck of the parison and suction through two tiny apertures in the mouth of the ring mould, which draws the glass home, giving perfect rings free from faulty tops, as any air lock is thus prevented and the homing of the glass secured.

When the blob has settled down, the air chamber attached thereto gives a supply of air to form the neck, and into this hollow later ascends the hollow air-filled tube with a bulb head called the plunger. This widens the neck and makes sure of its being set wide enough for machine and crown cork fillers. In due course the plunger is retired through the space its air spray has made and blowing is continued. The pressure of air for this work after extensive tests has been found best at 10 lb., the strength of a man's blow, as with this it has been found that necks don't crickle or become too brittle to stand the stress of high pressure bottling. The method is seen on the diagram and also the special air chamber. These air chambers follow round between the parison and shape mould, and at the bottom of the rotation, carry the blob from the parison to the shaper mould, and the punt former rises and solidifies the bottom of the bottle in the mould, when the blower then blows it up and returns to the parison in time for the next charge, having opened its jaws and left the bottle to continue its course till its 19 secs. is accomplished and it is ejected from the mould to the conveyer. The shaping mould should be most carefully polished and made of vanadium hard iron which withstands the temperature and does not wear quickly, preserving perfect joints and ensuring brilliant skins to the bottles, and have needle holes in the shoulder to let out any air caught between the glass and iron and so prevents indentations, inequalities, or malformations of the bottles. Champagne punts can be arranged by a small additional attachment and the necks may be made for screw stoppers by passing the plunger into the neck mould in the parison through a device giving it a spiral movement instead of a direct thrust, and withdrawing it similarly. The plunger and wheel can have that adjustment fitted to put on and off as wanted. When set enough in 19 secs. the bottle is dropped on to an asbestos covered steel band conveyor and through a tunnel passed into the lehr between reciprocating hard oak sides.

The conveyor to the lehr is syringed with water on its return from the lehr, so as to maintain the required amount of (22) moisture to prevent crumbling of the asbestos of which water is a component part ; and the tunnel is to prevent premature chilling of the outer skin of the glass, a source of continual trouble, and so securing a better equilibrium between the skin and interior stresses of the glass.

The plant is simple, entirely automatic, and virtually fool-proof, since it wants no handling in operating, and, if kept clean and well polished, has a very long life, as the parts are few and easily replaced if needed at any time, and the total outlay on machines, *i.e.*, gatherers, parisons, blowers, shapers, conveyors and lehr chargers can be refunded in 5 years by an amortization charge of little more than (c) 3d. per gross of bottles at 120 per min. The machines are 3 times as efficient in output as any present day outfit, have comparatively few parts, are economical in upkeep, entirely automatic even to " taking out " and " in," can be run continuously or intermittently, moulds can be changed without stopping the machines, all parts can be synchronized and made inter-dependent to regulate feed to output, to stop feed when machines stop, and go faster or slower according to temperature and cooling of bottles being made ; and being fitted on rails can all or in part be removed and replaced by spares in a short time.

The foregoing virtually deals with the glass shaping machinery. The heat and its utilization is all that remains, and Fig. 1 explains these at sight. The details of how each item is accounted is clearly shown by the formulæ in the appendix. To begin with, there is the heating up of coal, air and batch to 400° over the lehr heat, thereby cooling the glass and combustion products in the lehr by absorbing their heat.

The producer turns coal steam and CO_2 into CO (23), afterwards in the furnace to CO_2 and H_2O giving a heat of over 2,000° theoretically, and practically of about 1,800°. Fig. 5 shows this with its fuel chamber and rake, its two grates, one movable and the other fixed, its gyratory crusher and ash remover, steam air and CO_2 feed and rectifier basket at outlet of gas. When CO_2 is brought into the producer it brings with it sufficient heat to counteract the endothermic reaction of CO_2 to CO, extinguishing the incandescence, and permits one-third of steam to one of the carbon being added and burnt in the grate. This is used to drive in the requisite air to gasify the carbon, not accompanied already by oxygen, and to produce a sufficient draught to secure a pressure of gas above the coal bed of 2 ins. by water gauge.

Fig. 5.—The coal enters the producer from the coal retort which has removed all moisture and volatiles from the coal and made at the low temperature, a soft coke which is passed into an elevator and is crushed to the requisite $\frac{3}{4}$ in. to 1 in., and then passing through an airtight valve (indeed the retort and all crushers and valves from the coal bin are airtight) enters the fuel chamber made of tiles with a toothed front end. This levels the bed and closes up the holes or vents, which would allow the CO_2 from the coal burnt in the grate together with the CO_2 of the preheater to escape into the producer gas. The coal is drawn into the bed and allowed to pass 1 in. higher than in front by the shorter back tile of the chamber. The fuel chamber being tight, the carbon dust or soot that may have escaped the retort cannot get into the gas without passing through the fuel bed and becoming gasified. The CO_2 from the preheater comes off at 850° to 1,000° and is sucked out by an ejector and passed down its pipe inside the up-flue. The temperature of this not being less than 1,350° and not more than 1,500°, increases the temperature to nearly 1,200°, and then it is passed underground into the rotatable mushroom apex of the grate which spreads it all over the coal bed at the incandescent zone level at 1,050° or more. Until the coal bed fuel gets lower than

this apex mushroom, nothing interferes with or disturbs the gasification of the coal. The lower grate is of fixed super-imposed circular inclined plates with air spaces between each, amounting to about 1,000 sq. ins. through which diffused air and steam pass to combust the fuel of the coal bed. The producer is 10 ft. 6 ins. in diameter, 3 ft. 6 ins. ash zone, 3 ft. 6 ins. incandescent and coal zone, and 3 ft. gas chamber, gasifies from 20 to 30 cwt. per hour, and rotates 3/12 rev. per hour. On leaving the gas chamber the gas at about 700° must pass through a basket of quartz which catches (24) any dust or soot trying to escape and being above kindling temperature, burns it. Moreover the gas is driven against a circular baffle which causes any dust to fall into the dust box while the gases pass on and are joined by the ethane, methane and ethylene, drawn off in the retort. These, according to coal analysis, may enrich the producer gas from 30 to 50 per cent. The gas passes into a bustle pipe to be led to the burners, and in the centre of each burner is a small tube of compressed air which acts as an injector to the gas (and also compels air into the centre of the flame) which gets mixed with the air, both entering through spirals, one clockwise, the other the reverse, and so are thoroughly mixed before combustion in the funnel. At the firing end of these tangential burners a hole passes through the funnel wall to the outer air for taking pyrometer (25) readings and to be used if need be for admitting cold air to the flame to reduce the temperature when wanted. The gas if below 700° can be passed through the gas pipe in the recuperator and raised to nearly 1,000°.

The air to burn the gas is brought through iron pipes forming the roof of the lehr, which is above the heat of the hot glass entering at about 850° and below the combustion products, and so heated to about 450° to 500° it passes out of these pipes into the air conduits of the recuperator, and is raised to 800° as it passes out into the air bustle pipe to be burned in the burners already described. The air required is moderate in quantity, as, owing to the CO_2 and H_2O burnt from the CO and H_2 produced in the producer without nitrogen to heat up, heat to heat it has not to be got by combustion in the funnel, so the heat has only to heat up the nitrogen of the air of combustion, but that is enough, as it means heating 750,000 kilos (26) of nitrogen from N.T.P. to 1,800° at a cost of 0·25 kilo cal. per kilo per degree, or the equivalent in heat of nearly 46 tons of coal at 7,400,000 cals. per ton. No apportionment of heat is made between 950° and 500° as this is absorbed in passing through a 14 ft. × 8 ft. boiler with 81-3$\frac{3}{4}$ in. (27) tubes in three banks, which present 1,000 sq. ft. to the heat internally, and 200 sq. ft. externally, estimated to give 180 I.H.P. at 120 lb. pressure, and to evaporate 350 gals. water per hour, enough to generate sufficient electricity for all required motors and light, grinders, mixers, pre-heaters and retort. The compressor for air and burners and blowers should be 1,000 cu-ft. per minute. If oil is used (28) they would still be of sufficient capacity. Cold air douches should be available to turn on as required to gatherer and/or paramould, as it is essential that the suckers and moulds should be kept under such temperature as is required to prevent the glass and moulds getting sticky and adhering to each other or the temperature getting too hot for workmen to do their best in it.

For real economy cement and glass should be made at the same time in similar plant with duplicate funnels and a cooling rotary for cement clinker, because : (*h*)

1. The materials are identical, although in different proportions.

2. The amount of CO_2 got from the large percentage of lime in cement greatly reduces the coal bill ; 700 tons cement and 540 tons glass give 443 tons CO_2. That is enough O to turn its own 120 tons of carbon and another 120 tons from the producer coal bed to CO plus the steam to the weight of one-third of 48 tons burnt in the grate, and saves having to heat up air with three-quarters of it nitrogen to no good end to bring C to CO.

3. The coal consumption for the 1,240 combined tons being thus 168 tons plus a spare 32 tons for emergencies, call it 200 tons or less than 16½ per cent. coal to products in cement and glass, and finding at same time all power required from the waste combustion products. This fuel, in calculating for work is called *300* tons, and the per centage *25* to allow of a safety margin of 50 per cent.

Comparative Cycles same scale Cyclone & Square.

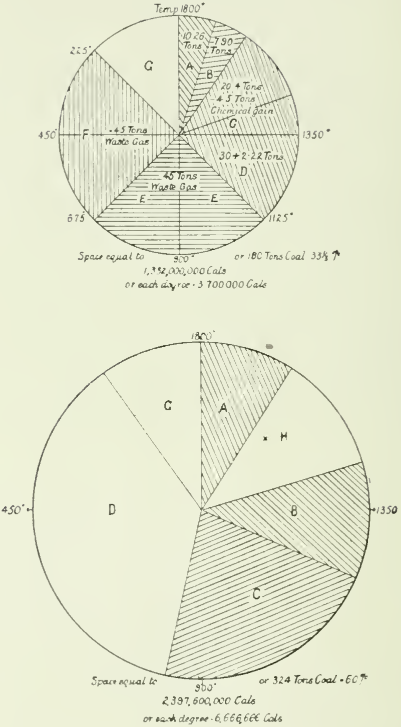


FIG. 7.

APPENDIX.

(A) COMPARATIVE DETAIL : Basis *Coal Average = 7,400,000 Cals. per ton. 4 Square Tanks =* 540 tons/324 tons Coal = 60% V. 30% 162 tons Coal for 540 tons *Cyclone = 2,397,600,000 Cals.* ∴*6,660,000* = 1 degree of Circle ∴ *3,330 000 = 1,198,800,000 Calories.*

COAL.	CALORIES.	WORK DONE (DETAIL).	CALORIES.	COAL.
	221,583,600	Melting Batch (7)	75,438,000	
	63,328,000	Latent Heat (8)	54,880,000	
	265,322,240	Chemical Heat (9)	—	gain
	64,600,000	Radiation prior to Melt (10) ...	1,913,587	
	64,600,000	Radiation during Melt (10) ...	2,709,404	
	749,952,000	Refining and Amalgamating (14)	12,096,300	
			147,037,291	
	1,429,385,840	This Total must be got above 1,350	32,359,360	Cr. Chemical gain
	968,214,160	To Regenerator under 800° Total	114,677,931	
= 324 tons	2,397,600,000	Preheating 400/1,000° (13) ...	79,967,000	
		Transfer through Iron (13) ...	24,492,000	
Consequently radiating 60% of the heat to incoming air it cannot give more than 480° to add to heat of combustion and flame temperature may not reach 1,800° more probably 1,650°.		Driving off CO2 reduces temperature to 850° (15)	—	
		Recuperation Air to 800° (15) ...	91,884,650	
		Recuperation Gas to 800° (15) ...	34,125,000	
		If both to 1,000° add (16)(17) ...	125,950,000	
		Preheating to 450/500° Batch ...	37,104,608	
		Retorting Coal	5,760,000	
		Preheating to 400/450° Air ...	172,500,000	
		Transfer through Iron	62,995,968	
The numbers in brackets refer to the calculation No. in the appendix.			747,457,157	
		Cr. heat from Glass (18)	54,880,000	
			692,577,157	
		Power 4)1,198,800,000 = say ...	300,000,000	+ 28 spare.
		300.000.000		
TOTAL ∴		134 tons Total less	992,577,157	
LESS		51 23 tons ex CO2	———	= 134 tons K.P.
		—— 29 tons ex spare	7,400,000	——
NET =		83 Nett —		=162 = 30%

Batches dealt with (cheap green bottles), (with disturbing $Al_2 O_3$) 5 $Na_2 CO_3$, 7 $Ca CO_3$, 4 $Al_2 O_3$, 1 $Fe_2 O_3$, 36 $Si O_2$ of which comes forth 5 $Na_2 O$, 7 $Ca O$, 4 $Al_2 O_3$, 1 $Fe_2 O_3$, 36 $Si O_2$ as glass and driven off as CO_2 = 83·48 tons = 23,131 Kilo C + 61,684 O = 84,815 Kilos CO_2. The chemical loss in the square tank is 265,322,240 Cals, or the equivalent of nearly 36 tons of coal, of the average of 7,400,000 Cals per ton, if, as is usual, the CO_2 is allowed to mix with the combustion products, plus the loss of the latent heat of gasification, plus the sensible heat to raise it to 1,000°, to be then immediately wasted up the chimney if not entangled in the glass mass.

(B) 120 Bottles p.m. = 1,209,600 p.w. of 168 hours.
Bottles 302,400,000 × 250 = 5 years of 50 weeks.
Gross 2,100,000 ÷ 144 = gross in 5 years.
At 1d. per gross = £8,750 to pay for Funnel Tank Preheater Recuperator Retort and Lehr structures.

(C) A further 3d. per gross = 26,250 for Machinery Moulds Producer, Lehr Conveyors, Lehr Producer and Preheater and Retort Mechanism, but excluding Tube or Hardinge Mills Compressors Boilers, Rail Connections, Batch and Coal Bins, Oil Tanks, Buildings (external), Warehouses and Working Capital, and Machine and Engineering Shops.
£35,000

(E) Glass is a combination of Silicates, which at a heat greater than the melting point, plus latent and chemical heat coalesces into a large molecule, and " sets " at about 850°. If suddenly cooled at that or higher temperatures it takes on an outer skin and imprisons the stresses of the inner mass, so that a small concussion is sufficient to destroy the vessel and break it up as the inner strain is enabled to escape.

(1) *Funnel diameters* below burners, 12′, 11′, 10′ 9½′, 9′, 8½′, 8′, 7½′, 7′, 6½′, 6′, 5′ 9″, 5′ 6″, 5′ 3″, 5′ = 14 ft. deep below burners = 366′ + 18′ tank = 384′ or 2 seconds travel of combustion gases at 175′ per sec.

(2) *Tube mills* at 60 mesh give 46% on, remainder finer, average 0·1 mm.; duty 172 tons in 24 hours, 10,000 lb. pebbles, for 22·5 I.H.P.

(3) *Surfaces* of a cubic metre laid on flat, 10 c.m. thick = 10,000 × 10,000 and 1,000 deep, or a surface = 100,000,000 units. Ground and sprayed into air = 100,000,000,000, or 1,000 times more, but multiply by sphere, *i.e.*, ½ volume × 3·1416 = 6,300 times, or 1,000 × 2 × 3·1416 times = 6,300 times, surface. Being only 0.1 mm. diameter, permeation to centre = 0·05 m.m. $\frac{1}{2000}$ part of 10 cm. laid on.

(4) *Combustion products* have a viscosity of ·000129 against Sulphur at 187° of 560. The nearest approach to melting glass, but as the gases are rarefied 7½ times the proportion is 129 to 4,200,000,000—but only referred to herein as 1,600,000 leaving safe margin.

(5) *540 tons glass want 629,000* Kilos Batch ÷ 604,800 seconds per week = 1·04 Kilo feed on per second or 2 lb. freed from CO_2.

(6) *Chemical Heat Account* :—

						H.F.				%
5 $Na_2 CO_3$	=	106	=	530	@	273,700 × 5	=	1,368,500	=	13·3
7 $Ca CO_3$	=	100	=	700	@	273,850 × 7	=	1,916,950	=	17·7
4 $Al_2 O_3$	=	102	=	408	@	392,600 × 4	=	1,570,400	=	10·3
1 $F_2 O_3$	=	160	=	160	@	195,600 × 1	=	195,600	=	4·0
36 $Si O_2$	=	60	=	2,160	@	180,000 × 36	=	6,480,000	=	54·6
In disassociating				3,958 Kilos—lose—				11,531,450		99·9

This to form glass, say slags as follows, all of which are well known

										%	M.P.
5 $Na_2 Si_4 O_9$	=	302	=	1,510	@	820,900 × 5	=	4,104,500	=	44*	1,050
7 $Ca Si O_3$	=	116	=	812	@	329,350 × 7	=	2,305,450	=	24	1,250
4 $Al_2 Si_2 O_7$	=	222	=	888	@	757,900 × 4	=	3,074,600	=	26	1,170
1 $Fe_2 Si O_4$	=	204	=	204	@	333,636 × 1	=	1,333,636	=	5·	1,040
Crown 2H, O				16				58,000		—	
										99·9	
				3,430				*9,873,246			
Driven off CO_2				528		Balance		1,658,264—being LOSS.			
				3,958 as above.				11,531,450			

Chemical loss = 1,658,264 × 160 for 540 tons = 265,322,240 in 4 tanks each 135 tons p.w.

The same 3,430 Kilos with 9,873,186 heat of formation comes from the Cyclone from :—

												% to funnel.
5 $Na_2 O$	=	62	=	310	@	100,900	×	5	=	504,500	=	9·03
7 $Ca O$	=	56	=	392	@	131,500	×	7	=	920,500	=	11·43
4 $Al_2 O_3$	=	102	=	408	@	392,600	×	4	=	1,570,400	=	11·90
1 $Fe_2 O_3$	=	160	=	160	@	195,600	×	1	=	195,600	=	4·66
36 $Si O_2$	=	60	=	2,160	@	180,000	×	36	=	6,480,000	=	62·97
				3,430						9,671,000		99·99

This produces instantaneously as above 9,873,246 under square tank.

or difference 202,246 × 160 for 540 tons

∴ = Gain 32,259,360 in the Cyclone of 540 tons.

Square tank *loss* 265,322,240 using 4 tanks.
Cyclone *gain* 32,359,360 ,, 1 ,,

In favour of Cyclone 297,681,600 Kilo Calories.

(7) *Sensible Heat* to Melt Sq. Tank 0·25 g.c. × 1,400° × 540 tons $\frac{3958}{3430}$ Kilo ... ... = 221,583,600
Cyclone, 0·25 g.c. × (1,400° — 850° preheated) = 550° × 540 ton × $\frac{3,430}{3,430}$ Kilos ... ... = 75,438,000
In favour of Cyclone 146,045,600

(8) *Latent Heat* to turn to liquid at melting point :—
Square tank 100 Constant × 3,958 Kos × 160, to give 540 tons or 633 batch 63,328,000
Cyclone 100 × 3,430Kos × 160, to give 540 tons or 630 batch to CO_2 not melted 54,880,000

In favour of Cyclone 8,448,000

(9) See (6).

(10) *Radiation* :—
Square tank 0·015 g.c.s. × $\overset{\text{cm.}}{6.45} \times \overset{\text{inch}}{144} \times \overset{\text{second}}{604,800} \div 1,000$ to Ko Cals. ×

562,464 = (useful constant)
7,628 sq. ft surface 64,600,000
Cyclone 0·015 × 562,464 × 113 + 113 sq. ft. surface 1,913,587

In favour of Cyclone 62,686,413

Radiation below 1,350°.
Square Tank 0·015 g.c.s. × 7,628 sq. ft. × 562,464 64,600,000
Surface
Cyclone Tank 0·015 g.c.s. × (37·30 × 3 + 113 + 270) × 562,464 2,709,404

In favour of cyclone 61,890,596

(11) See first page of Appendix, Comparative details.

(12) '*Pielet's factors of Radiation* g.c.s. surface to 0° from

100°	150°	200°	300°	400°	500°	600°	700°	800°	900°	1,000°	1,100°	1,200°	1,400°	1,400
1,	2,	3·3,	7,	12,	18·3	26,	35,	45·3	57,	70,	83,	100,	120,	150

intermediate temperatures use difference of factors, *i.e.*, 1,000° to 900° = 13.

(13) *Final preheating area,* 400° to 1,000°. Transfer through iron 0·14 g.c.s. × 314 sq. feet ... ... = 24,492,000
400° to 1,000° heating up in contact with plates ·20 g.c.s. × 600° × 633,000 Kos ... ... = 75,900,000
Latent heat evaporation of CO_2, 49 gc. × 83,000 Ko = 4,067,000
Driving off 84,815 Kilo = (528 × 160) C. 23,130
going to producer O. 61,685 = 12,311,018

116,770,018

These 116,770,018 Cals $= \frac{1}{12}$ of all 360°, $\frac{1{,}800°}{12} =$
150° lost from 1,000° leaves, 850° to funnel—
Heat absorbed 1,928 moles @ 97,200 = 187,401,600 + Latent 50 × 84,815 = 4,240,750 = together 2,191,642,350.
This CO_2 saves 23 tons coal and gives O for itself, and another 23 tons, and as there is no N. it saves heating up 103,000 Kos N. *i.e.*, 0.26 g.c. × 103,000 Kil = 26,780, *i.e.*, wasted calories.

(14) *Refining and Maintaining* 0.003 (g.c.s. by Radiant heat flowing over out of contact (therefore conductivity) × (50′ × 20 sq. ft.) × 100 c.m. deep × 4 tanks × 562,000
in square tanks = 749,952,000
Cyclone, Tank = 0·003 g.c.s. × 105 sq. ft. × 67 c.m. deep × 562,000 ... ... = 12,096,300

(15) *Recuperation* tiles $\frac{81}{144}$ × 144 divisions × 27 rows high. Transfer of heat 0·0015 × 300° diff. ×
81 × 144 × 27 = 2,187 sq. ft. = 9,842 × 562,000 = 5,534,650
144 × 1 × 1
+ *Heat to air* 0·25 g.c. × 300° × 1,154,000 Kos air by contact for reaction CO to CO_2 = 86,550,000
91,884,650
+ *Heat to gas* 0·25 × 100° × 200,000 Kilos by contact, CO, Cone & C × $5\frac{3}{4}$ = 1,365,000 = 34,125,000
126,009,650

(16) *If Air is required at 1,000°* instead of 800° add $\frac{2}{3}$ air figures ... ... = 57,700,000
(17) *If Gas is required at 1,000°* instead of 800° add $\frac{2}{1}$ of gas figures ... ... = 68,250,000
125,950,000

18) *Heat in Glass entering Lehr* if 460 Cals @ = 1,250° : 460 Cals : : 850° : heat of glass 372 Cals to give up.
∴ 548,640 Kilo glass × 372 Cals = 204,094,080 Cals to lehrs, or to each one half of it.

(19) (20) *Cold surface in gatherer* = 37·8 sq. inches, glass radiates 0·0122 g.c.s., and is 2 seconds in contacts and will loss 302,400 per week, *i.e.*, 11,407,893 : 302,400.
: : 1,400° to x = 4° temperature loses 4/6° to month of parison—In " *Parison* " 60 sq. inches., for 11 seconds = 266° lost = 1,030° remain ; in " *Shaper* " 80 sq. inches 200° loss = 830° to lehr to anneal.

(21) Latent heat in glass given up to lehr 548,800 × 100 included in (18) 54,800,000.

(22) Asbestos contains 14·48 % H_2O, which being driven out by contact with hot bottles and lehr heat is replaced by syringing with H_2O, as the belt returns from lehr.

(23) *See producer balance* sheet apart (23).

(24) *Kindling Temperatures* of producer contents CO, Coke, Anthracite,
644° 700° 700°
Carbon, H Methane, Ethane, Ethylene ∴ producer gases at
650° 580° 650° 520° 542°
700° will ignite all dust caught in quartz basket.

(25) Repeated tests with contact and colour *pyrometers* have resulted in a difference at 1,460° contact = 1,600° colour—that seems to mean flame 140° higher than area of furnace.

∴ 200° above melting point necessary in furnace to cover this and latent heat—in addition to chemical heats losses and radiations

(26) *Nitrogen* to be heated up to 1,000° in Producer = 79,349 C ex Coal × 4·444 for Kilo = 352,681 × 0·25 × 1,000° = 88,150,050 that is lost in producer.

When this is burnt in funnel repeat with 10% excess	=	98,065,000
Add same for temperature to 2,000° ...	=	98,065,000
		196,730,000

This causes a loss of flame temperature of over 300°, and makes any heat beyond 1,800° impossible, except N is partially absent.

(27) *Horsepower* ·178 Kilo Cals per second = one H.P. per second, 180 h.p. = 32 Cals per sec. = × 604,800 = 19,353,600 or with 50% margin = 38,706,600, and for this is reserved 300,000,000 Calories between 950 and 500°, between recuperator, Lehr and boiler 14′ × 8′.

(28) *Oil Burning* is equally suited to funnels as coal gas, and the labour attending both is equal as in the plant under review. There is no stoking or turning over. Cost is the sole question. 168 tons coal = 104 tons oil in efficiency. Say :—

Coal costs 30/- ton = £252 for 1,243,200,000 Calories.
Oil cost 80/- ,, £416 ,, ,,

or in larger funnels ½ oil and ½ gas at rate of £334 for 1,243,200,000 Calories.

Oil, however, when burnt with high temperature air, say 1,000°, gives a very high temperature flame (" but not so equally high diffused temperature ") and required a zircomum lining specially built into the bricks.

(29)

Producer Balance Sheet with CO_2 from Preheater,	Calories.
= 85,760 Kilo = 1,947 moles at 97,200 from 23,388 Kilo C.	189,442,800
Add Latent Heat in same at 50 per Kilo ...	4,288,000
,, Sensible Heat ·30 g.c.s. × 85,760 Kilo × 1,100°	28,300,000
,, in full work 110° extra or 10%	2,830,000
,, the coal supplied to CO_2 to make CO 23,288 to CO. @ 29,200	56,910,800
	281,771,600.
Deduct Chemical Heat on 1,949 moles × 68,000 ...	132,532,000x
	149,239,600
Add 79,349 Kilo carbon ex coal feeder to CO_2 = ÷ 12 = 6,613 moles @ 97,200	642,783,600
	792,023,200
Deduct for reaction to CO @ 68,000	449,684,000y
	342,339,200
Add 26,406 steam @ 173° 120 lbs. pressure = H. 2,935 O. 23,481 = 26,416	
Add 17,610 C to burn to CO with 23,480 O ex steam = 1,467 moles @ 29,200	42,836,400
	385,175,600

Add x in funnel recorded	132,532,000
,, y ,, ,, ...	449,684,000
,, z 1,467 moles @ 68,000 ex steam	99,824,000
	1,067,215,600
,, 26,406 H to H_2O @ 58,060 × moles 1,467 ...	85,232,080
	1,152,447,680

C used

23,388	Ex CO_2	to burn to CO & then to CO_2	7,400,000
23,388	,, feeder		
79,349	,,	for grate heat	
17,610	,,	for steam	
143,735	Carbon provided and used and Hydrogen to H_2O.		

Equivalent all but 156 tons.
120,347 Kilos coal subject reduction of heats supplied from re-utilization of surplus heats absorbed.

SQUARE TANK :—

214°	Melting Latent and Chemical Heat, Refining and Maintaining	1,429,385,840
146°	Balance to Regenerator at 730°.	
360°		

60% got back in heat = 438°.

IT IS IMPOSSIBLE .·. TO GET IT DOWN TO 760% AND GET 1,000° TO REGENERATOR SO TO GET THE BURNER TEMPERATURE UP TO 1,800°.

By Preheating	Reduce	Melting Quantity by 83 tons and save	40,000,000
and so	,,	Latent ,, 83 ,, ,, ...	8,500,000
and so	,,	get rid of Chemical loss in furnace	265,000,000
		Reduce depth of tank by ½° to 67 c.m.	250,000,000
			563,500,000
		from	1,429,385,840
		That is bring Calories down to	855,885,840

and heat at 1158° to Regenerator to give back 700° to fuel.

and do the business complete on 60% Coal, except *Power*.

CYCLE NOTES

1,350° A = Melting, *WG*.
B = Latent Heat and *Refining*, etc., *WG*.
1,125° C = Preheating to 850°, *WG*.
D = Recuperation in "Cyclone," *WG*. or Regeneration in "Square," *WG*.
550° E = Reserved for Power, *WG*.
225° F = Preheating to 400 Coal Air and *WG* batch.
G = To Chimney or for Dessication, *WG*.
1,350° H = Chemical Loss in "Square" tank of *WG* as against a gain in "Cyclone."

It will be noticed that neither power *E* nor *F* preheating, nor sufficient air and gas heating are provided for in square tank cycle. Some preheating is sometimes provided from non-waste gases.

The "Cyclone" melts and delivers the glass with 90 tons used for glass making actually, any surplus being for power.

The "Square" requires for same result 324 tons.

The air and gas of "Cyclone" are delivered at 1,000°.

The air and gas of "Square" at scarcely 450°.

See Comparative Utilisation figures, p. 1 of Appendix.

NG is fresh New Gas ex burners requiring highest temperatures.

WG is Waste Gas after highest temperature work is done.

"Cyclone" *efficient* with 90 tons nett carbon or 16 2/3 per cent. fuel or at 30s. ton or per week. *£135* stg.

Square" *inefficient* with 60 per cent. or 324 tons fuel or at 30s. ton for £486 stg. per week.

Square" efficient with 100 per cent. or 540 tons fuel or at 30s. ton for £810 stg. per week.

PRODUCER NOTE.

1·0 Carbon
0·75 Steam
1·85 CO_2

Make a balanced producer supply and give enough heat to melt to a liquid 22½ glass or cement, exclusive of radiation, transfer through iron, conductivity, resistivity, diffusivity and emissivity requirements, but CO_2 to become CO in presence of C, requires 760° to transform 75 per cent. of it or 1,050° to transform 99·5 per cent. of it to CO, using air with its 75 per cent N., the heating up of which absorbs so much of the heat of a producer without result other than that the heat put into the N goes into and through the furnace

DISCUSSION.

The **Chairman** said the subject which the author had put before them in such detail tended to accentuate the great variety of work into which engineering could be subdivided. The paper entered most fully into the highly specialised matter.

He had been particularly impressed by the large number of items which had to be observed in the manufacture of glass bottles and presumed the same number of items called for attention in connection with the manufacture of glass irrespective of what it was to be used for.

In one part of the paper, reference was made to the force of a man's "blow" when glass bottles were blown by personal wind pressure, and he presumed, although the paper did not say so, that the force of 10 pounds meant 10 pounds per square inch. He had no idea that human lungs could give such pressure, and perhaps the author would say how long a glass blower could keep up this enormous strain. The paper gave much detailed information regarding the subject and clearly indicated that the author had gone deeply into it. It therefore afforded him great pleasure to ask the meeting to accord him a hearty vote of thanks for enlightening them in the mysteries of glass production, and he trusted there might be several gentlemen present who would augment what the author had said so as to enhance the value of the paper.

Mr. E. A. B. Willmer said he had not had an opportunity of reading the paper beforehand, and hence had not thoroughly grasped the principle and operation of the machine, at least not enough to offer any criticism ; he had enjoyed the paper and could see that there were many novel, ingenious and interesting devices in the machine designed by Mr. Ferguson. He asked whether machines could be seen at work in this country, what would be the approximate cost of building and installing one of the machines. His experience had been that in this country at least machines of the Owens type and other rapid production automatic machines had not been a success. This was no doubt partly due to the large capital cost involved in their installation, the great size and weight of the machines themselves and the consequent high cost of operating and upkeep, necessitating a continuous high rate of production and a market for the same. This had not altogether materialised in this country. But on the other hand it was also due to the fact that not sufficient time and study was given here to the efficient operation and improvement of these machines, whereas in the United States of America, where he had had the opportunity of investigating the working of the Owens and other glass making machines for the British Government, he had found that much more attention was given to these points, and an efficient staff of engineers and mechanics was kept constantly studying and improving the working of the machines. The result was they were more successful. If Mr. Ferguson's machine could claim to be cheaper in capital cost, and in operating and upkeep costs, while maintaining an even greater rate of production, then it certainly was a big step in the right direction, and worthy of investigation.

There was only one point which at the moment occurred to him and on which he would like information. The author stated that the speed of the machine was equal to the production of 144 bottles per minute. This seemed to him to call for some special metal for the moulds to withstand the temperature unless there was some special means of rapid cooling of the moulds. The trouble with such machines always had been with the moulds when producing at such high rates, and difficulty had been experienced in getting the right composition for the metal of the moulds. Various mixtures had been tried with varying degrees of success, but there still remained much to be done in this direction. The author mentioned vanadium iron and it would be interesting to hear with what success this had been tried.

Mr. C. Saxton said he had received a copy of the paper only on entering the room and consequently had had no opportunity of examining the various revolutionary methods put forward, though after hearing it read, he thought that Mr. Ferguson must have gone very thoroughly into the whole question, but whether from the purely theoretical point of view alone, or whether the many practical difficulties had been considered, could only be answered after reading the paper several times.

In the first place he would like to know whether the methods proposed had been tried anywhere and if the figures put forward were the results of these trials or only what the author would like to obtain. The author had suggested the use of CO_2 as blast for the producer. This, he thought, had already been tried both in Germany and in France, but so far without any practical success. Possibly Mr. Ferguson knew of these attempts and had evolved a method of overcoming the difficulties then encountered.

Mention was made of the penetration of heat into the " filling on," as used in ordinary glass tanks. This old method, undoubtedly had its disadvantages, but it was being rapidly superseded by the use of a " Dog House " or small annexe built on to the melting end of the furnace. The use of this " Dog House " permitted of a practically continuous flow of raw materials into the furnace, to replace the glass pulled out by the machines at the other end. In this way the difficulties of heat penetration into the old fashioned " lumps " mentioned by the author were avoided. The speaker was entirely in agreement with the advantages claimed for the grinding of the batch. There was not the slightest doubt that grinding in this manner not only conduced to a lower fuel consumption per ton of glass, but also to a more homogeneous glass. With regard to the " Doctor " with the water cooled hoe for cutting off the tags of glass from the gatherer, he sincerely hoped he was wrong in supposing this to be a man, as if it were, he certainly was not to be envied when making 144 bottles per minute.

The author spoke of " a wave of rolling glass pushed along in front of the parison mould of an Owens machine," and stated that the " Owens always sucks in the same spot." With regard to the first statement, all he could say was that if the author had seen this, it was simply due to bad operation, as the speed of the revolving pot could be varied to suit that of the machine In fact there was no reason for any horizontal movement of the mould and glass relative to each other during the suction period.

Coming to the statement that the Owens machine always sucked in the same spot, if the author meant that the successive moulds always drew from the same point in the revolving pot, he (the Speaker) wished to say that this was not the case. In fact the revolving pot was introduced solely with the idea of presenting a fresh surface of glass to each successive mould and so avoiding the chilling, etc., mentioned by the author.

He also wished to refute the suggestion of the previous speaker, that the Owens had not been a success in this country. In perhaps one or two isolated instances that might be so, but it was due entirely to the factories operating them, and not to the machine, as was proved by the satisfactory results obtained at all the other works using them. The machine was undoubtedly expensive in first cost, or rather the auxiliary equipment and construction put up the cost, but from personal operation of the Owens and the various other types of machines both in this country and on the Continent, he could assure the meeting that the Owens could and was producing bottles in this country as cheaply, if not cheaper, than any other method, after taking all charges into account, and at the same time making a better bottle.

He did not think there would be any difficulty in cooling the moulds as mentioned by Mr. Wilbur, as he understood that the production of 144 bottles per minute was obtained by using 48 moulds, thus giving an output of 3 bottles per mould per minute, which was not as high as ordinary Owens practice.

Having only just heard the paper read, he had had no opportunity of examining the mathematical appendix to the paper, but thanked Mr. Ferguson for the trouble he had taken in working out, what if it proved a practical possibility, would be a revolutionary method of producing glass.

Mr. J. E. Lister, A.M.Inst.C.E., said that if the furnace and bottle-making machine described in the paper were a practical success they would entirely revolutionise the glass bottle-making industry in this country, as not only was the rate of turning out the bottles much in excess of anything so far attained, but the space occupied by the plant was much less than was required for the usual type of furnace.

He had recently come into contact with most of the types of bottle-making machines in use in this country, mainly in connection with the cooling of the moulds, which was necessary to enable the output to be maintained.

The question of the rate at which bottles could be turned out depended not only on the rate of cooling of the glass but also on the maintenance of the moulds at a sufficiently low temperature to prevent sticking of the glass. With an adequate supply of air there was no difficulty in maintaining a satisfactory temperature, either by means of internal ducts, as in the Owens machine, or by an external system of piping, as with the O'Neil, the Lynch, and the various types of semi-automatic machines.

He did not see any reason why the machine should not be perfectly satisfactory, as the general operation was similar to that of other machines which were working satisfactorily, though the author had applied the general principles in an entirely novel manner.

The soda was introduced into the lime and silica at a point where they had been preheated to 850°. Was this not above the melting point of soda, and would not there be a great tendency to stick in consequence ? Was there not a liability to considerable erosion at the zone where the batch first met the sides of the furnace ? The time taken by the mixture to reach the sides of the furnace was very short, and unless the batch was converted into glass molecules before it reached the lining, the erosion of the silica must be excessive. In an ordinary glass tank the life of the furnace was comparatively short, owing to the erosion of the blocks which took place, particularly at the level of the top of the molten glass. This erosion was probably of a chemical rather than a mechanical nature, but it took place most markedly where there was a distinct flow of the metal and where the temperature was hottest. In the Cyclone furnace the temperature was even higher than in the ordinary tank, and, as the furnace was smaller than the rectangular tank, the weight of the batch of metal rubbing against the lining must be much greater. If there were any uncombined particles of material the action on the lining was likely to be rapid. No doubt the reactions took place quickly, but an appreciable time must be taken by the heat to permeate the particles before the reaction could take place. In the ordinary tank it was advisable to cool the hottest parts of the glass level zone in order to reduce the erosion and prolong the life of the furnace. In the Cyclone furnace the lining was insulated, so that the blocks must remain at approximately the temperature of the metal. Unless the particles of molten glass absolutely protect the surface, the cost of maintenance would be high. This was a point that could be determined only by a trial on a practical scale.

He agreed with the author that the saving of heat with the Cyclone as against the ordinary tank furnace must be considerable. He had recently had occasion to investigate the loss of heat through the tank walls for the purpose of designing a cooling plant to keep the temperature of the inner surface of the blocks at a figure which was found to extend the life considerably, and some of the figures may be of interest. With new silicon blocks 12 ins. thick the external temperature under the gas ports was approximately 550-600° C., the natural air circulation at these points being restricted. Between the ports and at the end of the tank, where there was more natural air movement, the temperatures were about 350° and 300° C. The internal temperature of the tank was about 1,350° C. These temperatures would naturally increase as wear took place until the wall gave way at some point, and when reduced to, say, 9 ins., the heat loss of a zone about 2 ft. deep along the sides, and the free area underneath the tank was approximately 10,000 kilo-calories per hour. Allowing for the radiation from the crown of the furnace, the gathering portion and other parts not included in his (the speaker's) figures, the total loss given by the author in the appendix was approximately correct, and a considerable saving would result by the substitution of a Cyclone furnace with lagged sides and some use made of the waste heat.

He had already referred to the cooling of the moulds. Any men working near the furnace should also be provided with a supply of cool fresh air. The usual method was to have a series of " downcomers " arranged near the position usually occupied by each man, and a stream of fresh air was delivered by means of a fan to each workman. Something of this sort was absolutely essential, not only in glassworks but in other shops where work was carried on with hot materials, such as tin works, rolling mills and steel works, if work was to be carried on satisfactorily in hot weather. Separate plants should be used for cooling the men and the moulds, and it had been found in practice that a considerably higher pressure was required for mould cooling than for the ventilation plant.

The whole problem brought forward by the author was of considerable interest, as a great deal of the work seemed in the past to have been done by "rule of thumb," and our thanks were due to him for going so fully into the various questions.

Mr. W. M. Beckett, A.M.I.C.E., M.S.E., asked if the machine referred to had been actually constructed and tested, or if the figures given were only theoretical calculations.

The whirling and swirling action of the liquid glass referred to reminded him of the recently perfected process of making "spun" iron pipes by the Stanton Ironworks Co., and it would be interesting to know whether the rapid spinning of molten glass has been found advantageous in the manufacture of glass bottles.

Author's Reply.

The paper would have gone more fully into melting glass, but it was intended to deal primarily with the machine, nevertheless the criticisms on the melting plant are to the point.

The author pointed out to Capt. Lister that the soda (4 ozs. to 2 lb.) was filled in from a separate soda bin and at a lower temperature than its melting point. It was instantly dropped, along with the rest of the batch stuff, into the whirling vortex of flame. The time taken for the batch to reach the sides of the furnace was short, owing to the permeation being only 0·05 of a m/m., but it could only get there after the formation of weighty glass molecules which caused their expulsion by centrifugal force from the whirl. In practice it had been found that all the glass slag was cast out before the batch fell 3 ft. in the flame on to the upper and less inclined part of the walls. The reason, in the author's opinion, for the great erosion on the level of the top of the molten glass where it rose and fell, with alteration in the rate of drawing off, was due to the floating liquid mirror of unabsorbed soda silicate, which melts at 1,030°, eating its way into the bricks, and an unbalanced chemical feed of batch stuff. Cooling the outer edge of the melting glass, the author considers, is wrong in principle because the slow melting leads to devitrification, and turbid glass on the tank margin was slowly formed.

Good bricks stand up to 1,680° C., and do not give way to heat so much as to chemical action and physical friction. If one could put a higher temperature melting slag on the sides of the bricks on first heating up, there would be no erosion to speak of. This had been abundantly proved in cement rotaries. In the calculation of tank surface, allowance was made for all parts except the regenerators. The cooling of the moulds was an accepted proper course, and it was recommended in the paper. As there were absolutely no open ports, gathering spaces, or firing port from the glass in the Cyclone, the heat radiation was comparatively small.

In reply to Mr. Willmer, the author stated that he was not now a capitalist, and could not afford to erect and run such a plant for himself, but all parts had been separately tested and proved. The output gain and difference lay in the novel arrangement. The cost given by furnace builders for the entire structures was under what would be repaid by 1d. per gross on the output during five years, and for the bottle-making machine and gatherers about the same. The lehr, conveyors, retort rabbles, and batch preheaters, elevators and motors represented another 1d., and the boilers and electric generators for power for grinding, driving machines, disintegrators and producer another 1d., or about 4d. per gross. The cost of the machine alone was estimated at a trifle over £5,000. Most mould makers had their own mixtures for their metals, but the difficulty was to keep them so highly polished as to expand little, also to absorb the least heat, as highly polished iron absorbed only half the heat it otherwise did, and no metal could be so highly polished as Vanadium iron nor stand such a constant temperature.

In reply to Mr. Saxton, the author said he had had to study the treatment of slags in Sweden and South America long before he had any personal experience of British glass-making, and it was that experience, theoretical and practical, that he brought to bear on the glass problem. The method of melting had been tried by him with the late Dr. de Laval (of turbine fame) on slags in Sweden in volatilising lead and zinc and silver, and proved eminently satisfactory. The reactions were surprisingly rapid, the erosion of the funnel bricks over months almost nil, and the radiation insignificant, the consequent rate of melting rapid, and the homogeneity of the glass slags conspicuous, owing to all ingredients meeting the top heat at once. The figures put forward were compiled from authoritative and generally accepted physical constants proven in metallurgical work. In regard to CO_2, it was true it had been tried in Europe and America unsuccessfully, but that apparently was due to allowing it to be contaminated, in the first place, with combustion products, and, secondly, not sending it into the carbon at a sufficient temperature since at anything under 1,050° there was no complete reaction ; as stated, only 75 per cent. was transformed at 760°, but 99·5 was at 1,050° C., while at low temperatures the action was almost nil. The author was not ignorant of the "dog" house method of filling on, but wherever he had seen it it was heated by the glass from underneath already heated in the tank itself from fresh gas and, the greatest drawback lay in the CO_2 having to come off in the tank, and the consequently chilling down of valuable heat in the wrong place. In every case where the author had seen Owens machines at work he had always seen the wave of glass about a finger high in front of the travelling gatherer, and it was just this that suggested the destroyer stems to his gatherers. What was meant by always sucking in the same spot was clear enough, it always did, but the saucer revolved and gave comparatively fresh glass, though the edge of the saucer was not always free from the chilled metal falling from the glass tags along the edge of the saucer. The author admitted that Owen's machine was the best machine he had seen in the trade.

In reply to Mr. Becks, the generally accepted pressure of a glassblower's lung blow was as stated, and the author came to the figure named by a continuous trial, so overcoming the crickling of bottle rings, which occurred under the pressures demanded, and given by the mould and machine-makers' foreman investigating the cause.

On Monday, November 5, 1923.

G. A. BECKS, A.M.I.C.E., VICE-PRESIDENT,

IN THE CHAIR.

LUBRICATION.

By WILLIAM LEE (Chief Chemist of Silvertown Lubricants, Ltd.).

SOME knowledge of the physical and chemical properties of lubricants has become necessary to the modern engineer. So little is definitely known of the collateral qualities accompanying good lubricating power, so much diversity of opinion exists on the inference to be drawn from experiment, and such information as there is is so scattered, that (unless the engineer has ample time and is specially interested in the subject) it is likely to escape his notice. This paper merely attempts to collect some of what would appear to be the more important and least indefinite of the properties of present-day lubricants.

THEORIES OF LUBRICATION.

Very able men have brought forward theories to explain what takes place between bearing surfaces and a lubricant. These theories are mechanical, electrical, physical or chemical, according to the bias of the proposer's mind. They are on the fringe of the subject and do not help the engineer, because no method has been suggested as to how the postulated properties can be discovered and measured in the materials available as lubricants.

Practical observations on bearings indicate two types of lubrication which have been named " perfect " and " imperfect." " Perfect " lubrication is that which takes place when the design of the bearing, the speed, the load and the viscosity of the oil result in a substantial film being formed which is capable of lifting the journal into a " floating " condition. This condition is one which is desirable in every case. Generally, either the design does not permit of it, or it is practically impossible to attain it. The lubrication then becomes of the " imperfect " type, in which the stresses and other conditions are such that a very thin film of lubricant is all that is possible between the running surfaces, which, in this case, are on the verge of touching, and may actually, from time to time, come into metallic contact. The investigations of such workers as Beauchamp Tower, Thurston and Osborne Reynolds deal mostly with the "perfect" type of lubrication, and in the region of moderate loads and continuous motion. The other type, which at its limit has been called " boundary " lubrication, was investigated by Hardy, arises mostly with heavy loads and reciprocating moon. In practice the majority of lubricating propositions are an alternation of the two types, neither obtaining in its entirety. In " perfect " lubrication the load which can be carried increases with speed and viscosity, and a wide variety of lubricant and of composition of bearing surfaces are available. With an " imperfect " film the case is not a simple matter of speed and viscosity to carry the load ; much is seen to depend on the chemical composition of the oil and the composition and physical structure of the rubbing surfaces. Under severest conditions it is necessary to choose the best *lubricating* material as well as the best *lubricatable* surface. Apart from viscosity, lubricants have a selective affinity for one metallic surface, and different metals have different attractions for the same lubricant. Research has not gone far enough to yield much definite data, and a large field is open for systematic experimental investigation. There are signs that the field is about to be explored, but up to the present much theorising has been done on little experiment. Observation shows that good or " oily " lubricants, *i.e.*, those which will carry heavy loads under violent and variable stress, are absorbed into a bearing metal and adsorbed on its surface. There is thus presented to the load a layer not altogether liquid and not altogether solid. When, therefore, the metals of a bearing are forced closely together, so that some particles are whipped off, these particles are flung into the film with lubricant clinging to them. They cannot agglomerate and reach a dangerous size. A poor lubricant appears unable to segregate the worn metal which is dragged off, which has still the property of collecting other particles to it till deformation of the bearing surface becomes possible. An essential property of a lubricant is to " dirty " any abraded particle, and so prevent it doing serious damage. This property would seem to be displayed by even solids such as graphite, mica, sulphur and a few others. No doubt electrical phenomena are at the bottom of the matter. Good bearing metals are always alloys, never a pure metal ; the best results are obtained from alloys giving crystals harder than the mass surrounding them. Under great oil-pressure the soft parts yield first and minute depressions are formed which hold a supply of lubricant. This seems to be borne out by the fact that a well-running, heavy-loaded bearing is never brightly polished but has a mattness about its appearance. In fact, when a polished streak appears in a bearing it is usually a preliminary to a seizure. (Polished surfaces can, of course, exist under the conditions of " perfect " lubrication.) In practice cases are common where no lubricant, however " oily," has given satisfaction, but a change of bearing metal has resulted in good running. The reverse is equally true ; cool running has changed to hot on change of the composition of the metal. A careful choice of bearing metal, combined with systematic attention to boxes, packing and replenishment, has enabled railways to run efficiently on very cheap oils.

At the present moment it is not possible to do more than point out the importance of the nature of the bearing metal in regard to lubrication. Interesting work has been done on a few substances, and valuable investigations are in progress in the National Physical Laboratory, but much patient research is needed with heavier loads, higher temperatures and longer periods than has been attempted.

" Oiliness," whatever it is, is not always sufficient for good lubrication. Fatty oils are deficient in viscosity, and under heavy loads a thin saponifiable oil, though running coolly and with little apparent friction, will allow rapid abrasion of a bearing. The metal is abundantly though evenly removed in extremely fine particles. A mineral oil of the same viscosity would have resulted in heating, scoring and seizure. Suitable blending of mineral and fatty oil will generally give a lubricant which will avoid these evils.

Before proceeding to a short survey of the principal types of lubricants, it may be permitted to ask the engineer to consider more than in the past the inevitable frailty of oils, hydrocarbon and fatty, and to arrange for a thorough distribution of the lubricant to every part without unnecessary excess, exposure to heat, air, water and dirt. Heat and air are destructive agents to the essential properties of *all* lubricants. The right amount of the right lubricant is the ideal, certainty of application is essential, steady continuity of supply, preferably with the complete withdrawal of used oil. Contamination, with water, dirt, grease, should be more carefully guarded against than it is. Too great a variety of work should not be attempted with one lubricant. The lines of flow in lubricating film ought to be studied and the bearings designed accordingly. Grooves are cut unnecessarily and often wrongly ; in some cases they tap and remove the oil where it is most needed. The ratio of diameter to length is important. A long bearing cannot be adequately fed at one small portion of its length ; long narrow high speed bearings need ample clearances if the lubricant is to be taken in well and distributed to the ends ; very short bearings of large diameter are a mistake unless fed more than once in the circumference. In this case the oil is not carried right round, but takes a short cut to the ends. Grooves, if added, should collect the escaping oil and feed it back. In no case should they extend to the ends or enter the centre of pressure. If a shaft or journal has end play, much heat and many bearing failures are caused by inadequate end-thrust area and a wrong radius at the ends of the brasses. These should be nearly parallel to the radius at the root of the journal neck, and should follow the curve of a step bearing. With correct formation the lubricant coming from the journal is forced between the thrust surfaces, and keeps them apart. In internal combustion engines there is too great a diversity of oil distribution. One vehicle easily gives 1,000 miles to the gallon with no lubrication trouble, where another of the same horse-power and cylinder dimensions and general design runs from 200 to 300 miles per gallon and has many troubles.

Beyond the removal of comparatively small quantities of not very dangerous substances, the chemist does nothing to the natural petroleum products. He divides them into useful groups, but they are chemically the same when put on the machine as they were in the earth. The work of distillation and refining is mostly done in the country of origin, and, in non-producing countries as ours, the home work is practically confined to sorting and blending. Refining of lubricating oils from the chemical side stands essentially where it did nearly 100 years ago ; the same acid, the same soda treatments, the same filtration. Technically, great improvements have been made in methods of handling at all stages, in efficiency of works processes and in transport ; but chemically the raw oils can only be cleaned as it were, and cannot be economically transformed into anything better.

Lubricants.

These are of three classes—Liquid, Plastic and Solid. The liquids comprise mineral oils, fatty oils such as Olive Oil, Rape Oil, Lard Oil, Tallow Oil, Castor Oil, Fish Oils. The plastic include Petroleum Jellies, soft fats, greases composed of oil and soaps. The solids comprise Graphite, Mica, Talc. By far the largest class is the first, and of this the greater proportion consists of various petroleum hydrocarbons. This latter, being the most important division, will be taken first. We have to deal only with the heavy end of the series which constitute the lubricants. Almost every geographical area producing oil gives one differing from the rest, but for commercial purposes two broad classes are defined depending on the nature of the heavier residues or bases. On concentrating the crude oil in most cases one arrives at either a waxy, greasy semi-fluid residue, or a sticky, or even solid pitchy substance. The former have been called " paraffin base crudes," and the latter " asphalt base crudes." There is a distinct difference in the nature of the oils distillable from these two crudes. Paraffin bases yield lubricating hydrocarbons of low viscosity, high boiling point and high setting point, and then there is a gap until the heavy well-known cylinder oils are obtained as residues. The asphalt base crudes yield a long series of oils commencing with thin spindle oils and going on to thin engine oils, heavy engine oils, and then leave an undistillable residue of either fluid black viscous oil or a non-lubricating pitch. The asphalt-base distilled oils are characterised by lower boiling point, heavier specific gravity, lower freezing point, and an extension into very viscous engine oils of low freezing point. From whatever source arising, the commercial oils are obtained by fractional distillation of the crudes. The lighter oils distil off by heat alone, but after reaching a temperature of about 300° C. it is necessary to inject superheated steam in order to continue the distillation without decomposition or "cracking." The chemical constitution of lubricating oils is unknown.

REFINING.

Crude petroleum does not consist of pure hydrocarbons; otherwise it would, in all probability, be colourless. There are present compounds which give the oils a dark colour, a strong smell, an acidity and a tendency to darken, to form deposits, and even to corrode. Some of these compounds contain sulphur, a small quantity contain nitrogen, others contain oxygen, and others are of a highly unsaturated kind. By treatment with sulphuric acid most of these substances can be removed in the form of black acid tars, some liquid, some solid, but all insoluble in oil. To neutralise the acid substances, either originally present or formed, caustic soda solution is added, and the temperature raised, when a soapy solution separates out. After copious washing with hot water the oil is dried, and may be filtered with the help of some form of Fuller's earth. By these means the oil is rendered paler, more stable and constant in properties. In the case of some oils, particularly those from Pennsylvania, no acid is used, the oils being simply fractionated, the wax frozen out, and the expressed oil purified by repeated filtration. These are the so-called "Neutral Oils." In the case of other oils, the acid treatment may be slight; when we get "red" oils, or it may be very thorough, giving "pale" oils. The typical "paraffins" of Pennsylvania merge into the intermediate "paraffine" or mixed type of the mid-continent and western territory oils of the States, and then into the asphaltic crude of Texas and California. The Pennsylvanian field is practically the only source of neutral spindle oils, dark and red cylinder oils, and petrolatums.

The mid-continent gives, largely by "cracking" distillation, a series of useful machinery and engine oils, but no, or only inferior, cylinder oils. Latterly, by heavy refining, a series of useful cylinder oils has been produced from this field. They are not so good as the Pennsylvanian cylinder oils for high temperatures. Texas and California produce a series of spindle to heavy engine oils, some useful axle oil residuals, but much asphalt and fuel oil.

COMPARISON OF DIFFERENT TYPES OF OILS.

Sample No.	Sp. Gr. 60° F.	C.F.P.* ° F.	Viscosity.			C.T.* ° F.	Coke Value.	Sulphur %	I. No.*	Method. I. No.	Colour.
			70° F.	140	200						
				Russian Oils.							
1.	·914	400	3523	247	75	13	—	—	4·4	H.	—
2.	·9085	388	1228	130	52	10	0·23	0·14	5·2	H.	Pale.
3.	·8985	346	394	68	40	F.O°	—	—	8·6	H.	,,
4.	·890	296	150	46	—	,,	·034	—	10·2	H.	,,
5.	·911	320	1712	176	63	,,	—	—	14·5	H.	Black.
				Pennsylvanian Oils.							
1.	·855	358	147	47½	—	32	·057	0·049	18·0	W.	Very Pale.
2.	·862	372	261	62	40	30	·041	0·077	25·0	W.	Pale.
3.	·876	401	295	63	—	30	·044	0·197	15·4	W.	,,
4.	·893	529	6680	554	150	45	1·45	0·094	20·5	W.	Green Cylinder.
5.	·902	504	—	546	150	45	2·26	0·126	—	—	Dark Green Cylinder.
6.	·909	546	—	885	218	38	3·77	—	—	—	Brown Cylinder.
7.	·912	568	—	930	234	45	4.14	—	—	—	Black Cylinder.

* C.F.P. = Closed Flash Point (Pensky-Marten).
C.T. = Cold Test—Setting Point.
I No. = Iodine number. H.—Hubl.
W.—Wijs.
Vis. = Seconds, using Redwood's Standard Instrument.

COMPARISON OF DIFFERENT TYPES OF OILS—*Continued.*

Sample No.	Sp. Gr. 60° F.	C.F.P. ° F.	Viscosity.			C.T. ° F.	Coke Value.	Sulphur %	I. No.	Method. I. No.	Colour.
			70° F.	140	200						
PARAFFIN AND MID-CONTINENT OILS.											
1.	·876	396	278	63	40	30	0·059	0·118	—	—	Pale.
2.	·886	350	184	51	36	32	0·12	0·341	26·1	W.	,,
3.	·907	398	539	82	44	32	—	—	13·3	H.	,,
4.	·909	416	715	95	48	30	0·33	0·438	20·8	H.	Light Red.
5.	·917	430	1234	135	55	32	0·47	0·316	25·0	H.	Red.
TEXAN OILS.											
1.	·921	300	178	47	—	−8	0·17	0·257	30·0	W.	Very Pale.
2.	·934	342	751	85	44	5	0·35	0·354	27·3	W.	Light Red.
3.	·938	362	1583	128	50	5	0·25	0·426	21·4	W.	Red.
4.	·951	404	—	279	72	20	0·61	0·504	21·1	H.	,,
5.	·941	338	2720	208	66	0	2·57	0·664	26·3	W.	Black.
WESTERN TERRITORY CYLINDER OILS.											
1.	·926	495	—	805	167	58	4·07	—	—	—	Brown Cylinder.
2.	·916	496	—	700	164	—	2·01	0·318	15·5	W.	Green Cylinder.
3.	·916	510	—	930	200	32	2·1	0·365	20·7	W.	,, ,,
4.	·920	496	—	1080	213	32	2·62	0·372	19·0	W.	,, ,,
MEXICAN OILS.											
1.	·904	346	163	47	—	32	0·15	—	29·5	W.	Pale.
2.	·913	392	381	68	41	32	0·26	—	27·9	W.	Light Red.

Russian oils are the best of the important asphaltic-base oils. We have spindle, machinery, engine and heavy engine oils of good viscosity, good stability and low setting temperatures from Russia. Good axle oil residuals are produced, and most of the railway stock of Europe and Asia has been run on them in the past.

SAPONIFIABLE OILS.

Generally speaking the viscosities are low and very heavy loads cannot be carried without considerable wear. For the heaviest loads, blends of heavy mineral oils with suitable saponifiable oils are used.

VEGETABLE OILS.

Olive Oil is usually too expensive in the good qualities to be used as a lubricant. The common qualities are apt to contain too much free acid, resulting in wear, and gumming with metallic soaps. This oil when used in compounds not exceeding 3% of acidity, works well and does not readily oxidise.

Rape Oil is useful in axle oils, but too much must not be present, as it may oxidise and dry where bearings are warm. Packing of axle boxes can thus become as hard as wood. It is not the best oil to put in cylinder oils or internal combustion oils. When oxidised by warm air a highly viscous body is formed, which is not be used neat. Used in 10% to 20% mixtures, it is valuable for heavy work. It is not inclined to separate from mixtures when pure.

Cotton Oil is only useful when blown or thickened. It is more acid and more readily separates from mineral oil than does rape oil. Its chief use is in marine work.

Castor Oil is a valuable lubricant for heavy work. It is not usefully soluble in mineral oils, but it will dissolve 10% to 15% of most mineral oils. Such diluted castor oil is marketed under proprietary names. Castor oil can be treated so as to make it miscible in all proportions with nearly all mineral oils, and yet retain its lubricating properties. The process of solublising worked out by the author 15 years ago has been in constant use, and the improvement in the viscosity curve should be noted. Heavy Pennsylvanian oils partially precipitate this product.

ANIMAL OILS.

Whale Oil must be clean and of low acidity, say under 5% to be safe. It is useful in axle and journal oils, but its use as a lubricant is limited. It can be blown or thickened, but the product is inferior. It is rather acid, and does not give the viscosity given by rape and cotton oil.

Shark and Liver Oils generally can also be blown. Neithe the original nor the blown oils can be recommended as high-clas lubricants, though a small addition will confer an improved lubricating value on ordinary engine oils.

Blown oils are to be avoided in internal combustion engines.

Lard, Neatsfoot and Tallow Oils, if well chilled to separate stearine, well washed till free from acids, soaps and nitrogenous matter, are good lubricants and about equal. They are the best to put into cylinder oils, as they retain their greasiness to the last, and the asphaltum of mineral oils is dissolved or softened by them. Seed oils do not do this. Lard oil and lard oil blends give best results on turning, especially at high-speed repetition work. For this, if blended, they should be mixed with a pale high flash oil of similar viscosity.

GREASES.

Petroleum jellies are of limited application as lubricants. They should be chosen from the plastic varieties of high viscosity, say from 200 seconds upward at 140° F., using Redwood's instrument. They are apt to melt out and leave the bearing. Worked into wool packing they make efficient axle lubricants. Greases of the Stauffer type are semi-solid emulsions of moist soaps, usually calcium soaps, and mineral oil. The presence of about 3% of water is essential, otherwise the mixture breaks down into oil and hard lime soaps. They must not be melted except at the lowest possible temperature with great care, otherwise there is danger of separation. Their value depends on the percentage of saponified oil present, and the viscosity of the oil used. There is a tendency to keep down the quantity of soap, and to use too thin spindle oils. The best greases contain a high percentage (30 to 35%) of *soft* fats and a medium viscosity engine oil. By "best" is meant a smooth grease, adhering and long lasting. Stiffness is a bad criterion of value; plasticity and viscosity under load are most important. Softer greases usually contain less saponifiable oil, but an efficient grease does not contain under 12½%. Talc, china clay and earthy matters generally are to be looked upon as adulterants. Graphite and mica are expensive and legitimate additions in special cases. Greases with soda base should be used with caution. They are usually almost anhydrous and are rapidly broken down by water. In this condition they often cause rusting. Palm oil greases made of palm oil and soda, and as much as 50% of water, are a relic of bygone days. Rosin greases are deficient in lubricating power under load. So-called greases made of water, tar, clay, tar acids, fuel oil with or without lime and rosin, are to be found. Stauffer greases have no melting *point.* They soften gradually under heat, and a convention has to be made as to what shall be called the melting point. Greases are primarily intended for slow speeds and heavy loads

SOLID LUBRICANTS.

Graphite is well known. The natural grades must be examined microscopically, and by ignition, for the presence of grit. A valuable use of graphite is to give " skin " to cylinders, pistons, valve-spindles, and journals by rubbing well in, preliminary to a first running in. It assists in forming a lubricating surface ; it coats abraded particles and prevents their re-adhesion. Graphite is useful for slow and heavy work and for wooden bearings and gearing. Greases for this purpose should be high in graphite, and can be used very sparingly. Low percentage graphite greases, such as 5%, are almost useless. Oil or grease following graphite effectually removes it from the sphere of usefulness. The addition of graphite to a fluid lubricant increases the co-efficient of friction. Graphite used habitually will clog lubricators and oil ways, accumulate on piston heads and behind rings.

Mica of very good grade has a few of the properties of graphite. Its use is limited to greases, and it is sometimes present in dangerously large and hard particles.

Talc is to be avoided.

Grease Blocks can be efficient grease lubricants. The rubbing of moving parts drags off a thin layer of the block, and works it up into a smooth and soft grease. The hardness of a grease block is, therefore, only temporary. They are soap greases, specially prepared to retain their shape for convenience in handling and application. They should not be sticky when rubbed between the fingers.

COMPARISON OF VISCOSITIES OF CASTOR OIL AND MISCIBLE CASTOR.

Redwood. Viscosity at ° F.	Castor.	Miscible Castor.
	Seconds.	Seconds.
70	3750	2690
100	1105	994
140	340	360
180	139	168
200	98	125
212	81	105
250	54	70

PROPERTIES OF SAPONIFIABLE OILS.

Oil.	Sp. Gr. 60° F.	C.F.P. ° F.	Redwood.				Hubl. I No.	Oleic F.F.A.* %
			70° F.	140	180	212		
Rape ...	·915	450	405	105	68	53	100	1·5
Cotton ...	·923	493	325	84	52	40	110	0·25
Lard ...	·916	475	380	86	56	44	72	1·0
Neatsfoot ...	·915	480	392	89	58	45	70	1·0
Castor, 1st...	·963	500	3750	340	139	81	85	1·8
Whale, No. 1	·922	430	270	70	50	42	125	3·0
Coconut ...	·928	445	230	69	44	38	8·9	0·2
Olive ...	·916	478	400	98	66	50	84	3·0
Sperm ...	·880	480	137	51	44	41	80	1·2

* F.F.A.

ANALYSES OF TYPICAL GREASES.

Grease.	Dropping Point.	Mineral Oil.	Fatty Oil.	Lime. %	Water. %
Transmission	150° F.	84·8	12·0	1·2	2·0
Soft Cup ...	165° F.	81·0	15·0	1·5	2·5
Medium Cup	190° F.	79·3	17·0	1·7	3·0
Stiff Cup ...	205° F.	74·5	20·0	2·0	3·5

CHARACTERISTICS OF LUBRICANTS.

These are ascertained by the results of various "tests" applied to them. The following are the chief :—

Specific Gravity.
Open and Closed Flash Points.
Fire Test.
Viscosity at a series of temperatures.
Cold Test.
Colour, Odour.
Emulsibility.
Coke Value, ash content.
Iodine Value.
Sulphur content.
Acidity or Alkalinity.
Saponifiable content.
Volatility.
Asphalting rate.
Di-electric strength.

These tests are not required of every oil, but a selection is made depending on the purpose to which the oil is to be put.

A few are capable of exact measurement, such as the specific gravity, saponifiable oil, ash content, sulphur content, acidity or otherwise. Others are commercially obtainable within fairly close limits, viz., viscosity, flash point, fire test, cold test, dielectric strength, iodine value. The remainder depend on so many factors that no good quantitative methods have yet been devised. Work is being done in the direction of standardisation of all these tests, but no reliable method has been worked out for the coking test, emulsibility, oxidation, and the asphalting test.

1. *Specific Gravity.*—This is easily obtained by the hydrometer to within 2 points in the third place of decimals. The standard temperature is 60° F., and if the specific gravity is taken above or below that a correction of ·00036 per degree will closely adjust it.

2. *Flash Point.*—The closed flashpoint can reasonably be expected correct to about 4° F. Flashing point has little bearing on lubricating, and too much insistence is placed on it. The test is useful for identification and to discover contamination. A limit to the lowness of a flashing point has to be put, as under severe conditions the vapour tension has a bearing on continuity of the film. Moreover, a commercial oil which is prepared with ordinary care has within comparatively narrow limits a characteristic flashing point. The open flash point is 20° to 30° higher, and is subject in practice to greater variations owing to conditions of taking it not being clearly laid down or easily controlled.

The *Fire Test* or temperature at which the oil will continue to burn is not of much consequence. It is chiefly used by refiners for classifying the cylinder oils.

3. *Viscosity* is of great importance, as upon it depends the load a bearing will carry. Viscosity has to be fixed at the safe minimum in order to minimise waste of power. What this safe minimum is, is a problem of lubrication. It has to be found by practical trial. Viscosity is friction, and should be expressed in units of force, but as the rate of flow is a function of viscosity, the latter is expressed in seconds required for a standard volume to pass through a standard aperture under standard pressure. The instrument in use in England is the Redwood viscosimeter, which, though a great advance on the crude apparatus in use at the time of its introduction, is an imperfect instrument. The dimensions of the cup and height of the gauge point differ seriously in various instruments, and the bore of the agate jet has not the constant length and diameter requisite in an instrument of precision. It must be used with thermometers graduated for a definite and suitable immersion. Variations of 5% in results are found, and an all round error of 2% can be expected. Viscosities are sometimes expressed specifically in water units or in rape oil

units. Both these are fallacious and useless. The viscosity of rape oil is not a constant quantity even from seed grown in the same country.

In specifying viscosity it is advisable to state the requirements at three temperatures, such as 70° F., 140° F., 200° F. for journal oils, and 140° F., 200° F., 250° F. for cylinder oils. Of these the most important is that nearest to the temperature of working, viz., 140° F. for general lubricating oils, and 200° F. or 250° F. for cylinder oils. This one ought to be laid down within fairly close limits, say 2% below the stated figure and 5% above. The others serve to indicate the viscosity gradient. The oil which, other things being equal, has the least temperature-viscosity coefficient is preferable. Thick black oils have colloidal constituents, and at ordinary temperatures the time of flow is variable and generally meaningless as a viscosity indication. Low temperature viscosities take a long time to obtain, and are no indication of lubricating value. More latitude can be allowed to viscosity below and above the working temperature. The thinner an oil is below the working temperature and the thicker it is above, the better. Redwood viscosities at such temperatures as 300° F. and 400° F. are of little use, and their taking damages the viscosimeters

4. *Cold Test.*—This usually appears in a specification as a demand for " setting point." There are two difficulties here. The first is that there is no agreement as to the meaning of "setting," and the second is that there is no " point." Mineral oils when cooled down gradually become more viscous with or without the appearance of solid substances which render the oil more or less opaque. At low temperatures some oils become appreciably firm or plastic. They will reach this state over a range of temperature depending on the time allowed. The separation of amorphous or crystalline waxy substances takes time. Time must, therefore, be specified. Other mineral oils remain bright, but become extremely viscid down to a low temperature, and have an appearance like thick treacle. They are liquid or solid, according to the definition of solidity. An oil will be called fluid in a one inch tube, and set in a half-inch tube, or set in both of them, yet fluid in a two-inch bottle, which is sometimes used. It is necessary to fix a pressure, a diameter of tube, a definite low temperature, a time of exposure and a rate of flow under the specified head. It is not an intelligible question to ask " what is the setting point of this oil ? " but it is reasonable to ask " what cold test will it stand ? " Impossibly low temperatures are frequently specified for fluidity—temperatures not compatible with the rest of the specification. That is to say, it frequently happens that the specific gravity, flash point, and

viscosity curve can only be given by, say, Pennsylvanian oil; yet a cold test is applied which none of these oils will stand, and is only compatible with asphalt base oils, such as Russian or Californian.

5. *Asphalt Content.*—Asphalt is an oxidation product of all petroleums and has no lubricating value. It is present in all dark coloured oils. Its presence is objectionable in bearing oils if the quantity is large enough to cause separation of much solid matter likely to clog wicks, or otherwise stop the flow of oil. It is much more objectionable in oils for cylinders, especially those of internal combustion engines. Of itself it leaves about 45% carbon on ignition, besides causing stickiness and gumming. It is not fusible nor volatile. It is soluble in fatty oils, and its effect in steam cylinders can be counteracted to a considerable extent by the addition of 5% to 10% of saponifiable oil. Asphalt is absent from distilled oils, and the reddish coloured filtered cylinder oils, and nearly absent from many dark coloured cylinder oils; a reasonable limit is 0·5%. Asphalt can be produced in *any* mineral oil by oxidation during use.

6. *Coke Value.*—This is the percentage of carbon left on charring the oil in the absence of air. It is of importance in considering the suitability of an oil for superheated steam and internal combustion engines. Its accurate determination is difficult. The results by a careful worker are comparable among themselves if repeated and averaged, but can only be approximately compared with those of another worker. In any particular hydrocarbon series the coke residue rises with the viscosity. The number also varies with the series. It is not possible to give an invariably accurate arrangement of types in order of coke value, but the following is correct in a large number of instances:—

1. Manufactured colourless oils (lowest).
2. Neutral oils of paraffin series.
3. Russian oils.
4. Californian and Texan types.
5. Heavy "cracked" or dry distillation oils.
6. Very heavy asphaltic base oils.

Red oils give more than the corresponding pale oils.

7. *Ash Content.*—This is never high and in clean oils consists of a little oxide of iron and silica; sometimes nickel and vanadium and other metals. The ash percentage is of the order of 0·01%. Badly washed oils give alkaline residues, sometimes up to 2 %.

8. *Iodine Value.*—Is of great value in judging white and half-white transformer oils, but for others is only of use to the specialist.

9. *Sulphur Content.*—Sulphur is best absent, but is invariably present. It is lowest in good Pennsylvanian oils and many Russian oils, which contain about 0·01%. It is high in Texan oils, say 0·5%, and very high in Mid-Continent dry distillation oils, about 0·75%. There are exceptional oils of very high sulphur content, such as those of Lima and Ontario ; some oils, such as those of the Kimmeridge shale, contain 8 %. A high percentage indicates a poor or useless oil for lubricating purposes. The incidence of the sulphur content must be considered in relation to the type, and not by its gravitmetric percentage ; 0·25% would mean a poor paraffin base oil, but an asphalt base oil containing 0·5% would still be a good lubricant. Some sulphur is loosely held and is chemically active. It blackens silver and copper readily ; easily oxidises to acidity in presence of wet air and moisture. In this form it is deleterious. Other sulphur is hidden away in the molecules in stable combination. In this form it is doubtful whether it is harmful. It may affect the readiness with which the oil oxidises to asphalt.

10. *Emulsibility.*—A reliable quantitative method of comparing the rate of separation after thorough mixing with water is not at present known. For turbine and crank case oils a test is advisable, but the general appearance of the mixture of oil and water to an experienced eye is better evidence than a measurement of the amount of water separating after a given interval of time.

11. *Acidity or Alkalinity.*—Mineral acidity has disappeared from commercial oils ; organic acidity is invariably present, but is very feeble. Unless the organic acidity is active, and more than 0·25%, nothing need be said of it. Oxidised oils are more actively corrosive, especially when wet. For this reason circulation and splash oils need renewal. After drying they may be used for shafting bearings for a while.

12. *Colour and Odour* call for little comment. Red oils are less desirable than pale. Sulphurous odours are objectionable, and point to exercise of caution in use.

13. *Volatility.*—This is a much abused test. The test is a difficult one to standardise, so that repetitions can bear comparison, and the results are only of use in a limited number o cases. Transformer oils, which are required as fluid as possible, may lose 5% to 10% in a few weeks if the transformer is overworked and exposed to draughts. In the case of cylinder oils an excessive evaporation may be a confirmatory test showing suitability or not for work at a specific temperature. All hydrocarbon oils are mixtures, and a little of some lighter member may evaporate under certain conditions, while 99% may remain If the whole of the oil were to evaporate uniformly at the rate

determined by the experiment for a short time, the matter would be important. If a great evaporation were found, other tests of vital importance would be affected, and the oil should be rejected on them and not on the so-called volatility.

14. *Asphalting or Oxidising Rate.*—This property is highly important, and when a test or a series of reliable tests has been devised, valuable deductions may be drawn from the results. Asphalt, or sludge as it is sometimes called, is an oxidation product of petroleum, and experiments were made in the infancy of the petroleum industry on the rates of oxidation of various petroleum products. At ordinary temperatures all mineral oils absorb oxygen. The rate of absorption increases with rise of temperature ; the amount of asphalt, and other products formed in a given time, and under set conditions, varies with the type of hydrocarbon, and it is necessary to choose the more resistant types as working temperature rises and agitation or circulation of the oil is more violent.

When mineral oil is kept hot, and air is blown through, oxygen is absorbed. First, aldehydic substances and water, then resinous, and finally insoluble asphaltic substances are formed and left in the oil. The water formed passes off, along with numerous aldehydes. Formic, acetic, butyric and heptoic aldehydes and corresponding acids have been identified at the Silvertown Lubricants, Limited's, laboratories for some years. The aldehydes partially oxidise to acids, and the vapour coming from heated oxidising oil is very corrosive to metals. Copper, zinc, iron, brass are rapidly attacked. Iron rusts in a few minutes. The vapours contain active oxygen, and liberate iodine from potassium iodide.

The tendency to oxidation is important in the matter of suitable oil for internal combustion engines. There is a connection between asphalting rate and coke value. In a crank case oil is churned up, atomised and exposed to the severe heat of the piston and cylinder walls. The oil is oxidised according to the temperature, amount of churning and nature of the oil. Asphaltum is produced with heavy carbonisation when the cylinder is reached. There is an intermediate oxidation stage in the production of asphalt during which oxygen is absorbed but no sludge is thrown down. The oil at this stage also carbonises more heavily than the original. Again, if the coke value of an oil for these engines be taken, the number may be low, but if, after a short run, the value be taken again, it may be high. The really good oil, therefore, is not necessarily that which gives a very low coke yield, but the one which gives least after the contents of the crank case between consumption and making up have become approximately constant. This is illustrated by the following tests run on a test petrol engine under about half load.

PETROL MOTOR ENGINE OIL TESTS.

Type of Base.	Sp. Gr. 60°F.	C.F.P. ° F.	Red'd V. 140.	Asphalt. (Days.)				Coke before.	Coke after.
				1	3	4	6		
Russian	·907	390	160	0	0·12	0·08	0·13	0·61	0·607
Texan	·930	360	160	0	0·13	0·21	0·29	0·53	0·76

The Texan oil is steadily increasing, and ultimately passes the coking of the Russian oil.

COMPARISON OF ASPHALT AND COKE TESTS OF DIFFERENT SPECIFIC GRAVITIES OF SAME TYPE OF OIL.

	Original Oil.					*Oxidised Oil.*			
Type.	Sp. Gr. 60°F.	C.F.P. °F.	Red'd V. 140.	Asph.	Coke.	Sp. Gr.	Asph.	Coke Ox.Oil	Coke Asph. rem'd
Texan ...	·916	284	43	Nil	0·2	·932	1·45	1·82	0·8
,, ...	·945	404	225	,,	0·78	·945	1·72	2·23	0·97

COMPARISON OF ASPHALTS AND COKE VALUES OF DIFFERENT TYPES OF OILS, OF EQUAL VISCOSITY, BEFORE AND AFTER OXIDATION.

	Original Oil.					*Oxidised Oil.*			
Type.	Sp. Gr. 60°F.	C.F.P. F.	Red'd V. 140	Asph.	Coke.	Sp. Gr.	Asph.	Coke Ox. Oil	Coke Asph. rem'd
Pennsylvanian ...	·876	424	130	Nil	0·677	·877	Trace	1·03	1·02
Paraffin ...	·914	408	135	,,	0·67	·915	1·91	2·02	1·37
Russian ...	·910	386	130	,,	0·18	·910	0·41	0·506	0·47
Texan ...	·940	356	123	,,	0·21	·941	1·54	1·18	0·73

COKE VALUES AND ASPHALT TESTS ON FILTERED CYLINDER OILS BEFORE AND AFTER OXIDATION.

Oil used.	Sp. Gr. 60°F.	Red'wd V. 200°F.	Sulphur %	Coke before.	Coke after.	Asphalt before.	Asphalt after.
Pennsylvanian Cylinder ...	·894	150	0·094	1·45	3·0	Nil	Nil
Western Cylinder No. 1	·916	164	0·318	2·01	3·62	,,	,,
,, ,, No. 2	·916	200	0·365	2·1	3·86	,,	,,
,, ,, No. 3	·920	213	0·372	2·6	3·98	,,	Trace

The oils were heated to 250° C., and air blown through for three and one-half hours.

Economic Use of Lubricants.—The Pennsylvanian type of oil is not found in many places or in large quantity ; pale paraffin oils of high flash point and viscosity are not over plentiful. It is economically sound to use these oils only when indispensable. A good broad division of the application of types is as follows :—

1. *Pennsylvanian Type.*—Circulation oils, open transformer oils, steam cylinder oils, *i.e.*, where there is much exposure to air and warmth and easy demulsification is necessary.

2. *Paraffin Oils.*—Engine, shafting and other cool lubrication generally ; closed transformer oils.

3. *Asphaltic Oils.*—(1) Naphthenes, such as Russian, pale and lighter specific gravity types of asphaltic base oils ; as bases for internal combustion oils, also for ring lubrication, machinery and engine work and refrigerator oils. (2) Higher specific gravity and red asphaltics, heavy engine oils, marine engine oils, etc.

This division is rough, and in practice it is necessary to blend various types to cover all cases.

SPECIFICATIONS

ought to be wide enough to cover a choice of satisfactory lubricants, and should not contain accidental and unnecessary exactions. For instance, if the highest flash point is insisted on, the choice is limited to classes 1 and 2 ; if low, the cold test is specified ; then the third class is indicated. The rest of the specification should agree with this restriction. A few special observations are made with due reserve :—

CYLINDER OILS.

1. *Steam.*—For high temperatures only Pennsylvanian oils are available. Specific gravity from 0·885 to 0·915. For wet steam and low temperatures Western Territory oils are useful. Specific gravity from 0·915 to 0·930. These latter are more volatile, more prone to oxidation, and give more carbon than the Pennsylvanian oils. For superheated steam, in the past, cylinder oil stock was concentrated beyond the most economical point. Good oil was removed and objectionable matters concentrated in the residue. A flash point of 530° F. is not too low, and a viscosity of 220 seconds to 230 seconds at 200° F. Redwood is ample. Oil ought to be sprayed in and not allowed to trickle over hot metal at long distances from where it is needed. An oil film on metal at a high temperature is asphalted and dried by the admission of air. A percentage of 5 to 10 of *animal* oil is a safeguard. Cleanest lubrication is obtained from compounded filtered Pennsylvanian cylinder oils, in spite of their moderate viscosity and flash point. The quantity required is rather more than with black oils.

2. *Internal Combustion Engines.*—Here the rule is to use the thinnest oil which will give an efficient film, in order to minimise carbonisation.

Petrol Engines.—Most engines of this type are over lubricated with too thick an oil. Gumminess and high carbonisation are inseparable from high viscosity.

Diesel Engines.—This is an essentially three-oil proposition—cylinders, bearings and compressor. There is a strong desire to use one oil only, with the result that at best the oil suits the bearings. It is too carbonaceous for the cylinders, and too thin for the compressor. The best compromise demands Pennsylvanian oil only, which is economically unsound. Asphalt base oils, suitably blended with Pennsylvanian oils and preferably slightly compounded, are satisfactory in the cylinders and on the bearings. Only heavy filtered Pennsylvanian oils should go into the compressor. This oil should be compounded to deal with the warmth and dampness, and should be used sparingly. Texan and similar oils rapidly oxidise to asphalt, etc. All types become acid during use in compressors.

Automobiles.—Better grades ought to be used than for commercial vehicles. Paler oils of lower viscosity are preferable to darker of the same class.

Gas Engines.—Suction gas engines need heavier oils and must be compounded to deal with damp gas and dusty air. One grade for town gas and suction gas engines is often asked for.

Turbine Oils.—Pure Pennsylvanian oils are necessary for best results. Heavy asphaltic base oils are to be rigidly avoided. Red paraffin oils are generally added to the Pennsylvanian oils. They are best omitted ; they oxidise readily, sludge up and are high in sulphur. Low cold test cannot be insisted on below 30° to 35° F.

Axle Oils.—By far the largest part of this work is done by dark residuals or blends of distilled oil and residuals. It is unnecessary to use filtered or red oils. High flash points above 330° F. are not essential except for engine axles. Both asphaltic and paraffin base crudes give good oils.

Specifications should give at least two viscosity temperatures, one of which is about 140° F. At 60° F. to 80° F. the viscosity is uncertain.

DISCUSSION.

Mr. Bernard Martin said that in the early part of his paper the Author referred to theories which had been brought forward to explain what takes place between bearing surfaces and a lubricant, and remarked that " no method has been suggested how the postulated properties can be discovered and measured in the materials available as lubricants." Methods have not only been suggested but actually used in practice to measure "oiliness." At the International Air Congress in London last July, Dr. T. E. Stanton, of the National Physical Laboratory, read a paper on "Boundary Lubrication." Dr. Stanton's experiments show clearly that "boundary lubrication" is enormously influenced by the addition to Mineral Oils of small quantities of free fatty acids. The speaker then quoted from the editorial article of *The Engineer*, dated July 20, 1923 :—

> "The most striking instance afforded by practice of the insufficiency of the Reynolds theory is, in our opinion, presented by the known effect of adding small quantities of fatty acid to mineral lubricating oils . . . . . . to take some figures recorded by Dr. Stanton, *figures which are amply borne out by practical experience*, the addition of 1 per cent of oleic acid to Bayonne oil, an amount quite insufficient to have any noticeable effect on the viscosity, reduced the coefficient of friction in a bearing by no less than 17 per cent."

This reported a definite measure of "oiliness," which had been observed by many other experimenter's beside Dr. Stanton.

Mr. Wilfred E. Gooday, A.R.S.M., D.I.C., M.Inst.P.T., said Mr. Lee deserved to be congratulated on the compression into so small a compass of so large an amount of valuable data.

It might be assumed, from that part of the paper which concluded with advice for the making of specifications, that the information presented was sufficient to enable the average engineer to draft his specification for an oil which was required to meet definite operating conditions. If this conclusion were fully justified, we should not agree with the object of the paper, as in the present state of our knowledge it was impossible to measure in terms of a few physical and chemical tests those elusive properties of oils by which they are rendered efficient lubricants. We might regard oil specifications as falling into two categories. The first of a purely *protective* character. A specification of this type should preclude the possibility of accepting oils which for one reason or another would be totally unfitted for the intended service. Into the second category fell those specifications in which an attempt was made definitely to select an oil for a given purpose. These might be termed *selective* specifications, and it was with these latter that progress was at present impossible.

As the refiner of petroleum products had to admit that he could not himself devise satisfactory specifications of this selective type, the conclusion was that engineers and other experts in different branches of industry were beset with even greater difficulties in making such an attempt.

Another point which attracted the speaker's attention was Mr. Lee's expression of acidity. Here was a simple example of the possibility of confusion. Although we understood amongst ourselves the terms in which Mr. Lee expressed acidity, it was not definitely stated in the paragraph referred to, and, as he was aware, we could translate acidity in terms of milligrammes of potassium hydrate, percentage sulphuric anhydride, or percentage oleic acid.

Reference was made to the constancy of composition during the refining processes. This was practically true in the case of lubricating oils prepared to-day, but it was not inconceivable to the more imaginative or romantic of us that just as the " cracking " processes had been applied to crude oils with the object of increasing their yield of petrol, so such similar decomposition methods might be applied in the preparation of certain types of lubricating oils.

The Author's Reply.

In reply to Mr. Bernard Martin, the Author said that under the necessity for compression of references to theories of lubrication, sufficient and justifiable prominence had not been given to the fact that a considerable reduction of the co-efficient of friction was produced by the addition of small quantities of fatty acids to mineral oils, but the matter had not been carried sufficiently far into the realm of practice, and for a long enough time under working loads and conditions, for any definite action to be taken. The properties of the mineral lubricant chosen for the addition of fatty acids were still of paramount importance, and he pointed out the danger of the addition of anything more than the smallest percentage of fatty acids : large quantities, beyond—say—3 per cent. undoubtedly brought serious trouble in their train. The author had this fatty acid question in his mind when, in the early part of the paper, he referred to the desirability of further experiments under actual working conditions, as the connection between the laboratory experiments and large scale practice was not definitely established. A mere reduction of a co-efficient of friction, which was already a small quantity, by 17 per cent. was not of itself of great commercial value. At its best the " discovery " resulted in confirming the practice of those manufacturers who had always recommended the addition of saponifiable oils to lubricants wherever practicable, with the further consolation that they need not, in the future be so particular as to the neutrality of the fatty oils used. They might, therefore, freely use grades which were cheaper on account of their higher acidity. As to other theories of lubrication there was no need to justify further the statement made concerning them.

In reply to Mr. W. E. Gooday, the paper was not intended to induce engineers to launch out on the making of specifications of their own, but it was hoped that it would be useful in helping them to revise existing specifications so as to make them more in accordance with the properties of actual oils.

With reference to cracking for producing lubricating oils, the author was not aware that any oil could be usefully cracked for the production of lubricating oil, but that what lubricating oil was present was liable to be cracked into lighter oils. Lubricating oils were obtained from processes which proceeded to destructive distillation, but there was no evidence that the useful lubricants were produced from otherwise less useful material.

The Chairman had remarked that to him it appeared that lubrication consisted in forcing a layer of oil between two surfaces so as to separate them. If, therefore, lubrication was successful it would be a matter of indifference as to what metals constituted the bearing surfaces. For "perfect" lubrication the conditions were as stated by the Chairman, but usually in practical lubrication the thickness of the film was only a few molecules, in which case the nature of the bearing surface undoubtedly counted, as was indicated in the early part of the paper.

Monday, December 3, 1923.

A. STEWART BUCKLE, M.INST.C.E., VICE-PRESIDENT,
IN THE CHAIR.

RAILWAY SURVEYING BY PHOTOGRAPHY.

By J. W. GORDON, K.C.

THE system of land surveying which I am to have the honour of bringing under your notice this evening is based upon a theory of generalised linear perspective, and is therefore applicable in a wider field than that in which its use will be illustrated to-night. It holds the field, so far as I have been able to learn, against all other systems of treating photographs hitherto proposed, for, although the generalised theory of perspective has long been before the mathematical world, it has been embodied in a system not readily applicable in the form of measuring and drawing appliances, and has been regarded as a branch of higher mathematics, not as a department of applied science. In a book with which I came before the public in January of this year, the subject is presented in its practical aspects, but it is the generalised subject. In that book, therefore, it is exhibited as specially applicable to photographs from the air, the most general form in which the perspective picture takes practical shape. This evening its application will be limited to the case of photographs taken from terrestrial stations, for in railway surveying the use of aircraft will be of exceptional occurrence, being, for the most part, excluded on the ground of expense and not called for by the practical necessities of the situation.

The problem, then, which it is proposed to discuss may be thus proposed. Given a line as nearly straight as may be, but bending from time to time to right and left, connecting two terminal points, it is required to produce a contoured plan of the ground through which the line passes, including in the survey the surface lying within 50 ft. of each side of that central line. The survey is to be made by means of photographs, in the production of which a camera mounted on a tower ladder, or raised otherwise to a suitable height above the photographed surface, is employed, the datum level being maintained by means of a level stationed at one end, or other convenient point or points of the line of the survey. In utilising the photographs a comparator constructed on a new principle is used to determine contours, and a plotting board—also new in principle—to delineate the plan. These two instruments embody the principal results of three years' research, and other novelties, introduced either as apparatus or as method, may be grouped around them as accessory contrivances. Such, with a supply of pickets and some common instruments, such as a compass, is the instrumental equipment of the expedition, which dispenses altogether with theodolite and plane table and, almost entirely, with trigonometry.

The personal staff in the field consists of two, or it may be, three trained officers—a surveyor in general charge, a photographer in charge of the camera and photographic equipment, and a surveyor's assistant in charge of the level. The rest are bearers, of whom a larger or smaller number will be required according to the distance from a base, the nature of the ground, and other circumstances bearing on the physical difficulties of the expedition. The number of draughtsmen and computers employed in the office in the work of contouring and plotting, will depend upon the time limit fixed for completion of the work. It is one of the incidental advantages of this system that the office work is so simple that it can be easily split up among as many office assistants as it is economically advantageous to employ and so time may be saved to any extent when the saving of time is of importance. To this point I call attention because I am particularly anxious to disclaim any similarity between my system and the system originated in Germany, which has been much talked about in recent months in connection with the cartautograph of Hugershoff, and an imitation of the cartautograph recently put forward by Zeiss. That instrument is hardly likely to commend itself to practical men for it costs as much as a mansion in Mayfair to purchase, and is impracticably slow in operation, since only one operator can use it at a time. Moreover, every photograph treated must be completely dealt with in that instrument, even although hundreds of photographs may enter into the survey. It may be supposed therefore, that no railway contractor is likely to give it a second thought. I should do my cause a great injury if I failed to make it clear that I am not talking about either instrumentality or system in the least resembling this German invention.

Mention has been made above of a tower ladder to be used for providing camera stations. Such a support is used to give the camera the necessary extent of outlook over the country. For contouring it is a great advantage that the optical axis should be horizontal or nearly horizontal, for that is a condition of things which makes the observation of contour heights particularly easy. In railway surveying that is a consideration of prime importance, and it alone, if considerations of expense were not peremptory, would exclude the general use of photographs from aircraft for railway surveying.

It may suffice, by way of dealing with these matters, to reproduce here the instructions which were drawn up for the conduct of a test survey, upon which the present paper is based. The following are the instructions referred to :—

1. The ground is divided into two sections. Section A runs from Level Station A to a point intersected by the course line from Level Station B. Section B runs from this point of intersection to the end of the surveyed line.

2. The surveyor will lay out camera stations at intervals as nearly as conveniently possible at 300 ft. distant from one another along the course, the stations being as nearly as possible in line with one another in each section. He will denote every station by a picket.

3. The surveyor will record on the photographer's log the number of the camera station, a reference to the page relating to that station in the surveyor's log book, the date of the survey, the estimated length of the stage terminating at that station, and any other particulars which he may consider proper so to record.

4. The surveyor will prescribe rules to be observed in orienting and levelling the camera stand, with a view to obtain a trustworthy record of positions of the several camera stations.

5. The photographer, upon taking up position at a camera station, will see to the orienting and levelling of the camera, and will, whenever possible, place the camera in the survey horizontal plane. In so doing he will be guided by information signalled to him by the observer at the level, and when it is not practicable to place the camera in the survey horizontal plane, he will note the deviation therefrom, above or below, as the case may be. This note he will record in his log. If the camera has been successfully placed in the horizon of the survey that fact is to be similarly recorded. This notification completes the photographer's log.

6. The photographer, having completed his preparations, will take two photographs from every station—except the first and last. With these exceptions, one photograph will be taken forward and the other backward along the course. From the first station only one photograph will be taken—looking forward along the course. From the last station only one photograph, looking backward.

7. The level observer will set up the level in the position, and at the altitude prescribed by the surveyor, and will be constantly in attendance to give the survey level to the photographer at every station and to the surveyor whenever required.

8. The duty of the bearers will be prescribed to them by the surveyor.

A few remarks will suffice to make the bearings of these instructions clear.

No. 1.—When these instructions were drawn up we proposed making our survey, with the proprietor's permission, at a property in the North of London. The disagreeable attitude of a tenant, however, made it necessary to seek accommodation elsewhere, and this instruction has no bearing on the case at Gatton Park.

No. 2.—The camera used on this occasion has a focal length of 7·196 ins. and a semi-vertical angle of 18°. On level ground, therefore, if it were raised 30 ft. above the ground plane, its foreground would extend to within about 90 ft. of the camera station foot, say, to within 100 ft. of that point. If the optical axis be placed horizontal, the background would, of course, extend to infinity, and a point in the landscape 700 ft. away would appear in the photograph at 1·88 ins. from its foreground edge. Similarly, a point 400 ft. away would appear at a distance of 1·65 ins. from the foreground edge. We should thus have two stages displayed in this photograph, the nearer in a strip 1·65 ins. in breadth constituting the foreground of the picture, the farther off occupying 0·23 ins., lying immediately to the background of this foreground strip. The foreground of 1⅔ ins. furnishes the material from which plotting is done by the aid of this photograph. The background strip of this photograph will have travelled down into the foreground of the next photograph in order, and if it all lies at the assumed datum level, it will take its place regularly in the foreground of that later photograph. But any point that lies above datum level will travel too far into the foreground, and any point that lies below datum level will not travel far enough into the foreground. It is upon the extent of this travel that the calculation of contour height from parallax is based. These are the considerations which the surveyor has to take into account in laying out the stations and prescribing the angle under which the photograph from every several station shall be taken. On a hillside he may shorten the stage or prescribe an angle which will bring his optical axis into some desired relation with the ground plane and other considerations, such as the obscuration caused by wood and other obstructions to a clear view of the country, will enter into his calculations. The rule of 300 feet to a stage can be modified to suit all such requirements.

No. 4.—There are two independent methods of determining the position of the camera stations (*a*) the observation of them recorded by the surveyor in the log of the expedition, and (*b*) the determination deduced by plotting and contouring from the photographs themselves. The surveyor, by chain, telemeter, or otherwise, estimates the distances between stations, and the observer at the level determines their several altitudes and reports them. These estimates serve as a check upon the work of the draughtsman when he comes to deal with the photographs on the comparator and plotting board. It would seem, however, that the independent observations of station levels can well be dispensed with.

No. 5.—The work of the expedition is recorded in two logs, one a comprehensive log kept by the surveyor, the other a log of special matter recorded by the photographer on the photographic plate at the moment of exposure. The photographer's log serves to connect the photographs in a series and to record those data which the draughtsman will have to be furnished with when he comes to deal with the plates. The surveyor's log completes the record by notes on all other points which are proper to be preserved in the form of a log.

No. 6.—The reason for taking two photographs from every station, one looking forward and the other backward, is the obvious one that any salient object, such as a wall or a bush, although it may be overtopped by the camera and therefore not suffice to close the vista, will shut out more or less of its background, and, therefore, to get a complete picture, it is necessary to photograph a given area from both directions. In open country, however, the need of backwardly directed photographs is less than was supposed when the instruction was drawn up.

No. 7.—There are four datum levels in addition to the horizon plane, which come into consideration in the making of a survey by photography : (*a*) The reference plane, being an imaginary plane parallel to the horizon plane and situated at a distance equal to F. (the assumed focal length) below the nodal point of the camera. This is the plane for which all the numerical formulæ employed by the draughtsman in contouring and plotting, are computed ; (*b*) the map datum, being a plane parallel to the reference plane, but not, of necessity, coinciding with it, which is assumed as reference plane for the purpose of plotting from the photograph, and which determines the scale of the map when plotted ; (*c*) the survey level, which it is the business of the observer at the level to keep and to which the several camera stations are referred ; and (*d*) sea level, to which eventually all geographical levels are referred.

This cursory sketch of operations in the field may suffice to indicate the sort of work that has to be undertaken and the strength of a surveying party. We may now proceed to follow the opreations in the drawing office.

The photographs having been developed, the first thing to be done with them is to compare them for contouring. This is preliminary to plotting for the simple reason that the plotting scale has to be adjusted to the various levels of the photographed surface, and this adjustment cannot be made until those levels are known. I believe that it would be correct to say that by all writers hitherto on the subject of surveying by photography the problem of plotting has been treated as the simpler of the two problems, and the attempt has always been made to discuss the plotting of level surfaces as if it were a real practical problem. Obviously it is nothing of the sort. To attack the problem of photographic survey in this fashion is to put the cart before the horse. In fact, the problem of contouring is the simpler of the two, as well as being a necessary preliminary to the other.

The comparison may be done in various ways. The result aimed at is to compare a calculated with an observed parallax, and the parallax here in question is the displacement forward from the background into the foreground of the perspective plane when photographs taken from successive camera stations are compared by observing the position of some given object in each picture successively. That displacement will evidently depend upon the following factors :—

1. The height of the camera station above the object.
2. The horizontal distance of the object from the plumb point of the camera in the datum plane.
3. The horizontal distance, measured towards the horizon, traversed by the camera between the two camera stations to which the two photographs correspond. The travel of a point on datum level is easily calculated from these data. For, putting—

F = the focal length of the camera.
mF = the altitude of the camera station (No. 1 above).
A_1 = the distance of the object from the plumb point of station No. 1 measured in the reference plane.
A_2 = the distance of the object from the plumb point of station No. 2, similarly measured.
S_c = the distance between the two plumb points just mentioned.
σ_c = the displacement in the photograph of that datum level point ; we have for the photograph here in question—

$$\frac{\sigma_c}{h} = \frac{S_c}{A_1 - S_c} \quad \dots\dots \quad (1)$$

The photographs to which this formula applies are photographs taken with the optical axis horizontal. If the optical axis were inclined, we should have—

$$\frac{\sigma_c}{h} = \frac{S_c}{(A_1 + \tan\theta\, F) - S_c} \quad \dots\dots \quad (1a)$$

where θ is the angle of dip of the optical axis, measured downward from the horizon plane. In its second form the computation is just as easy as in the first if the angle θ is known as we may assume that it is known. In the case of a survey made from a terrestrial station it can be measured by clinometer and entered in the log. In the case of a photograph taken from aircraft it is ascertainable by the aid of beacons suitably arranged on the ground or photographically projected into the picture.

The value of σ_c varies, in every pair of pictures, with varying horizon distance. In fig. 1 we have a photograph by the side of which is placed a curve showing, by its ordinates, the extent to which any point on a datum plane $7 \cdot 18$ ins. below the horizon of the photograph would be displaced in the companion photograph (Fig. 2). The distance between camera stations on the ground was in this case 8 ft., the altitude of the camera station above survey datum $12F = 86$ ins., and the distance below the horizon of the map datum $\frac{12F}{12} = F$. Hence the map, if plotted on the reference plane, would be on the scale of 1 : 12, and the distance between the two plumb points would be $\frac{8 \text{ ft.}}{12} = 8$ ins. Putting the constant $S_c = 8$ ins. in equation (1), and giving to the variable A_1 a suitable series of values, we obtain the curve shown in Fig. 1, taking for its ordinates the successive values of σ_c. The values of A_1 are easily determined by the formula $A_1 = \frac{p^2}{h_1},$ where $p = F$ in the case we are considering, and h_1 is the distance of any given point in the photograph from its horizon line. The curve drawn was actually computed for eleven values of A_1 ranging from $A = 8''$ to $A = 47''$. These points being plotted, the curve was completed graphically. The horizon line in this case passes through the (approximate) middle of the photograph. It is identified by the fact that it here intersects the optical axis, indicated by the four fiducial points impressed on the plate at the moment of exposure. Consequently, the curve has its vertex in one of the parallels of the photograph itself, and indicates displacements into the celestial as well as into the terrestrial foreground. Being thus equipped with what I have ventured to call a parallacter for connecting these two photographs of Figs. 1 and 2, we proceed to compare them. For convenience of reference one of the photographs is divided up into $\frac{1}{4}$ in. squares, which are identified by being consecutively numbered, and every square in succession is contoured by reference to one or more points on it, which are taken to represent its level. The equation to contour height is—

$$\frac{C}{mF} = 1 - \frac{h_o \, \sigma_c}{h_c \, \sigma_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where $\frac{C}{mF}$ is the height of the contoured object above survey datum compared with the altitude of the camera station, and σ_c is the observed parallax when the horizon distance in Fig. 1 is subtracted from the horizon distance in Fig. 2. The comparison can be made with great nicety. Astronomers have carried such comparisons to great perfection, to a nicety, in fact, for which the railway surveyor is never likely to have any use.

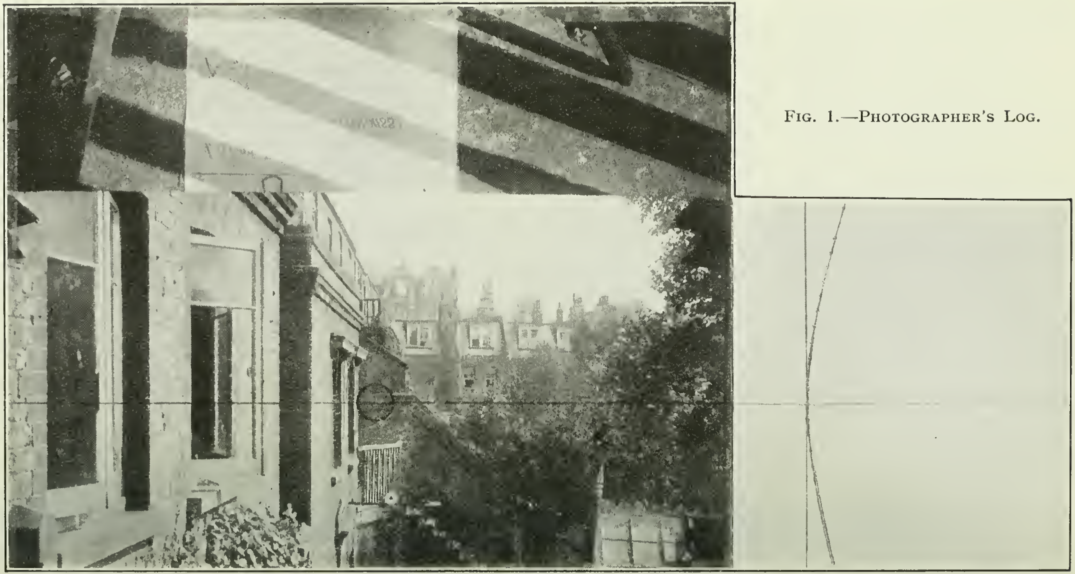


Fig. 1.—Photographer's Log.

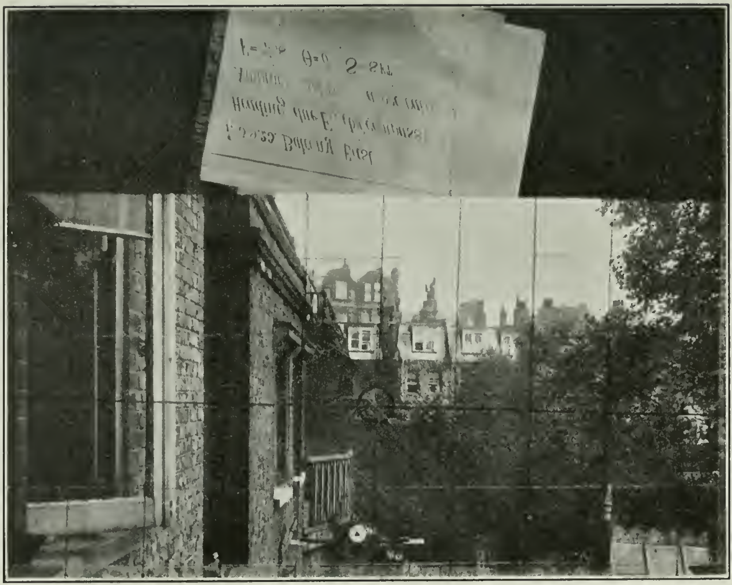


FIG. 2.
PHOTOGRAPHER'S LOG.

HORIZON AND
OPTICAL CENTRE.

Comparisons such as are called for in this connection present no difficulty and occasion but little trouble.

The photographs having been contoured, with whatever closeness is stipulated for by the paymaster of the undertaking, are now ready to be placed upon the plotting board. The principle of the plotting operation may be defined loosely in a word by saying that it is effected by means of a modified pantagraph. That is to say, there is a spotting point which is carried over the photograph and deposited on any spot which it is desired to plot, and a spotting arm for carrying the spotting point ; while, connected with this spotting arm, so as to move parallel with it, is a plotting arm carrying, or controlling, a drawing point or pricking point by which the plotting is actually done upon the plan. The photograph being mounted in due position on the board, this parallel movement of the two radial arms suffices to produce a correct plan, provided that the radial lengths of the two arms respectively are properly proportioned. It is the great merit of the device that the actual operation of so proportioning them can be easily explained and even more easily performed. The theoretical explanation is already before the public in the book above mentioned. It will be more interesting here to explain how the theory is applied in practice.

Fig. 3 is a photograph of a plotting board with a piece of squared paper mounted upon it. The spotting arm is made transparent, and carries a fiducial line traced along the middle of it which is used for spotting. The plotting arm, on the other hand, is provided with a working edge in line with the pivot point on which it turns. This edge serves as a guide for the plotting point, pencil point or needle point as the case may be, which is pressed up against it in the act of plotting. The radial distance of the plotting point from its pivot point is found by the aid of the hyperbola and straight line shown on the plan side of the board.

The condition to be satisfied is expressed by the equation $1 + \frac{R}{p} = \frac{p}{p -}$; where r is the radial length of the spotting arm and R that of the plotting arm. If in this equation we put $p = 1$ we may rewrite the equation thus : $1 + R = \frac{1}{1 - r}$

$$\therefore \quad (1 + R)(1 - r) - 1 = 0.$$

In this last form it is the equation to a rectangular hyperbola referred to rectangular co-ordinates, drawn parallel to its asymptotes, and having their origin in the apex of the curve. In that case we may write $R = x$; and $r = y$.

Hence the hyperbola can be used to connect the two radii r and R ; for if we take a point of which the ordinate measures r/p

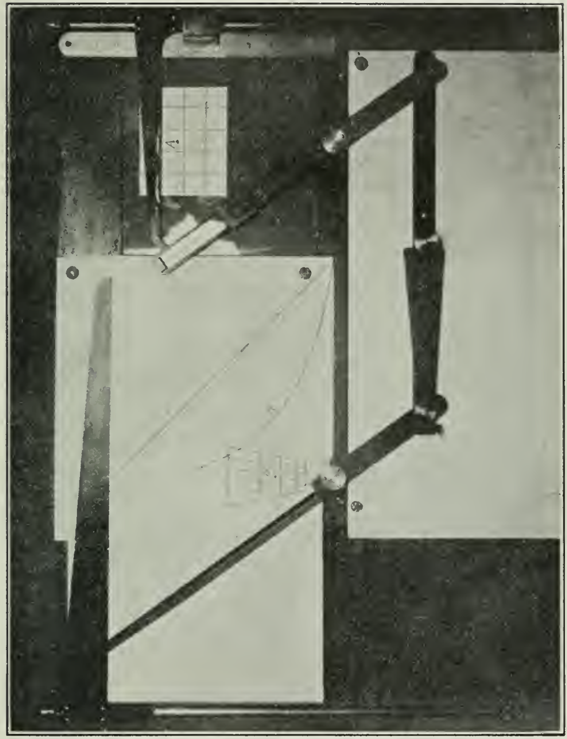


Fig. 3.

we may obtain $\frac{R}{p}$ from the abscissa by inspection. Since R and r are, by hypothesis, parallel, and the one is equated to the ordinate, the other to the abscissa of the curve, it is necessary to employ some contrivance for bringing into comparison these two last mentioned lines which are at right angles to one another. The angled straight line serves this purpose. If placed at an angle of 45° to the two lines compared it would subtend equal lengths on both and would serve to identify in the hyperbola a point having an ordinate equal to r. Then the abscissa of that point would be equal to R. It would be inconvenient in this case to plot the plan on that scale, which, as above stated, would be 1 : 12. To meet this case the form of the connecting curve has been modified by substituting an hyperbola having reduced dimensions along the x axis. A curve so modified is shown in

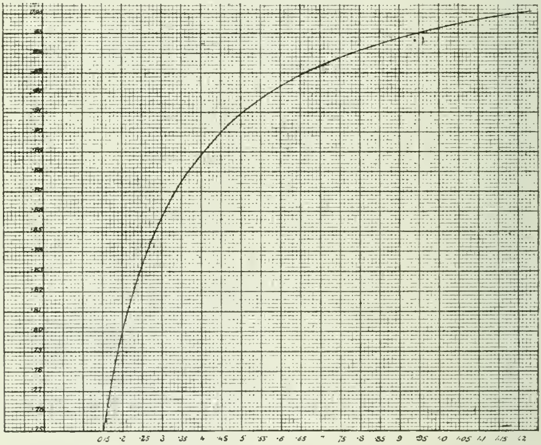


FIG. 4.

Fig. 4. In this figure the ratio between the two co-ordinates is expressed by the equation $(1 + 20x)\ (1 - y) - 1 = 0$. This is the curve which, slighly changed in Fig. 3, and used for connecting points in the photographic with points in the cartographic field, gives the plan upon a reduced scale as shewn. In that case the reduction of scale is to 1/10th of the scale of the photograph, so that our plan is here on a scale not of 1 : 12 but

of 1 . 120. For practical use a model curve is prepared which has the magnitude 10 ins. for the distance of its asymptotes from its co-ordinate axes, its equation being $(1 + 20x)\left(1 - \frac{y}{n}\right) - 1 = 0$. In this curve an arbitrary value is assigned to n, such that it gives a figure to the curve which is convenient for use. The ordinate $\frac{y}{n}$ is not to be treated as a "graph," but simply the representative of a quantity, the "graphic" value of which would be $\frac{y}{n}$ if y were made equal to 10 ins. On that understanding it is quite immaterial what value we give to y. If it is made actually less than 10 ins. all the values of the variable n will be reduced proportionately, so that the fraction $\frac{y}{n_1}$ for any given absciss length, $20x$, remains unchanged. Hence the ordinates inscribed upon the y-axis of the curve are expressed, not in inches, but in terms of $\frac{y}{p}$ where p signifies the parameter not of the hyperbola, but of the photograph. In making use of the model curve we identify the required ordinate with the fraction $\frac{p-h}{p}$ derived from the photograph where p is the parameter of the photograph and $p - h$ the parameter distance of the given point. The curve itself then yields to inspection an abscissa equal to $\frac{X}{20}$ when X is taken to be the parameter distance in the normal cartographic field, on the assumption that the parameter of the photograph is 10 ins., and the scale of the plan 1/m. If we wish to vary these assumptions ; if, for example, the parameter of our photograph is 7·196 ins., and the scale of our plan is to be 1/10 m., we must give to our working curve (1) inscribed upon the plotting board (1) abscissæ of corresponding dimensions. For example, in the supposed curve we should, in place of the abscissa $x = \frac{X}{20}$ of the model curve use the modified abscissa $x_1 = 0{\cdot}7196 \times \frac{20}{10\,m}\,X$. This use of the model curve will be illustrated in practice in a later paragraph. We may return to Fig. 3 in order to demonstrate the plotting board method of employing the inscribed hyperbola in the plotting of a plan. We may take the plotting of the point A in the "photograph" as an example. A line parallel to the horizon is drawn from this point across the photograph, intersecting the spotted point, and is carried across the map until it intersects the mediating line in the point a. From this point a vertical line, *i.e.*, a line parallel to the prime vertical of the photograph is drawn to meet the curve in the point a_1 and from the point so identified a second parallel to the horizon is drawn. Where this second parallel is intersected by the edge of the plotting arm is the point a_2 in which the given point in the photograph is to be plotted in the map.

The hyperbola and mediator line shown in the figure suffice for the plotting of all points upon a given level. Other points, lying at a higher or lower level, must be plotted by a curve on a different scale. The photograph, as we have seen, is subdivided into squares, each of which has been separately contoured in the comparator. Thus every part of the photograph can be plotted by means of its appropriate diagram, and the whole worked into a map of uniform scale upon which the contours already determied are suitably recorded.

The programme of a test survey having been set out the author proceeds to report upon the results of a test made as above proposed.

Arrangements were made by the kind permission of Sir Jeremiah Colman for an expedition to Gatton Park on the 20th October last. In accordance with the plan, it was part of the arrangement to hire a tower ladder for use on the occasion. But on our arrival at Gatton Park on the appointed day we learnt that the tower ladder was not forthcoming. Someone had blundered, and our tower was reported astray in London when it should have been at Merstham Station. That was very disconcerting, for our company and photographic and surveying equipment were all on the spot, and to crown all, the weather was most propitious. The opportunity clearly could not be thrown away —tower or no tower—and we therefore decided to survey down a slope where the natural gradient would put us in the position of being able to overlook from the ground level of our camera station an area lying as much below us as the level ground would lie if photographed from a tower.

The circumstance was not, in the end, so unpropitious as it seemed in the first moment of disappointment. The carrying out of a survey on sloping or undulating ground is, in the ordinary methods, especially troublesome, and has been assumed to be similarly troublesome, even in an extreme degree, if attempted photographically. It will be observed that in our proposed operations, as set out in the earlier part of this paper, we intended to rely much upon a dumpy level to keep us informed as to the levels of successive camera stations. We were quite prepared to deal with the case of a long slope or pronouncedly undulating country which would necessitate the moving about of the levelling instrument as a special and specially difficult case.

This was the case that was now presented to us at Gatton Park. We were provided with a level, but should have to dispense with its use in the directing of our photographic operations, for our first stage would take us quite out of the field of the level telescope, and if we were to carry through our amended programme time would fail us to make use of the level in the intended way at all. The only use which it seemed that we should be able to make of the level was to identify a point in the distant landscape which would serve as horizon point in dealing with our photographs, and that, for the rest, we must proceed by dead reckoning to connect the level of one station with those of the stations adjacent to it fore and aft. This, which reads like a counsel of despair, turned out to be a revelation of the capabilities of contouring by photography. The dead reckoning is astonishingly accurate, and both plotting and contouring in undulating country can be carried out by means of photographs with a despatch and completeness of which the plane table surveyor has never dreamt. These points are illustrated by means of a pair of photographs obtained at Gatton Park. But before proceeding to that subject, two more words of explanation may be interposed here. The first relates to our experience of the photographic apparatus. For reasons which have no bearing on the present subject, and therefore need not be detailed, it had been decided to use a magazine instead of dark slides for introducing our plates into the camera. The decision was ill advised. Its risks are illustrated by the event. When all seemed to be going well, the fourth of our plates when being transferred from the front to the back of the magazine broke in the changing bag. This was fatal to further progress. The broken plate could not be placed in position at the back of the magazine, but had to be left in the changing bag, where, of course, it prevented the further circulation of plates in the magazine. This trifling accident, therefore, brought our photographic operations to an end. In future we shall use dark slides and not a magazine for exposing our plates.

The second point to be noticed is the enormous scale of a photograph taken near the ground, and the necessity of taking that into account in making a plan from it. The scale of the photograph is proportioned simply to the altitude of the camera station, for the variation of scale due to perspective is allowed for in the plotting operation. Now a plan to a scale of 1/2500 (26 ins. to the mile) is equal to that of a photograph taken 2500 F. above the photographed area. The camera which we were using has a focal length (F.) of 0·6 ft. To produce a photograph by its means on the scale of the large scale ordnance map the camera would have to be raised 1,500 ft. above the level of the photographed ground. If we reduce that height to 50 ft.

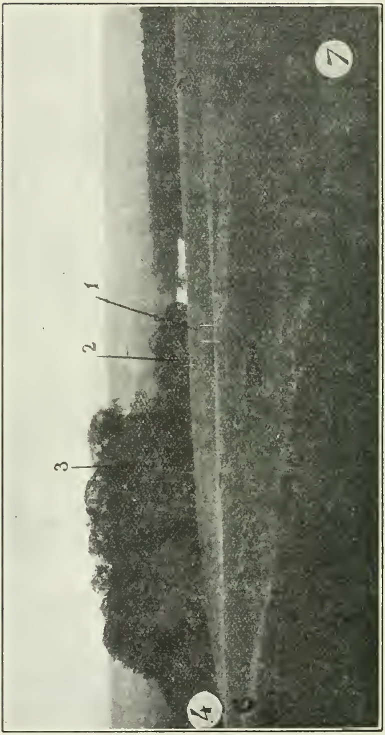


Fig. 5.

we get a map to a scale of 75 ins. or upwards of 6 ft. to the mile, a scale suitable only for dealing with very small areas. For railway surveying something very different is required. The modification of the scale presents no particular difficulty, but if the scale of the photograph is large the area represented in any one photograph will be reciprocally small. The number of photographs to be produced and dealt with is proportionately great. This is the only inherent difficulty in land surveying by photography. It disappears in hilly or deeply undulating country. It has to be surmounted on level country by the use of a portable tower or equivalent device.

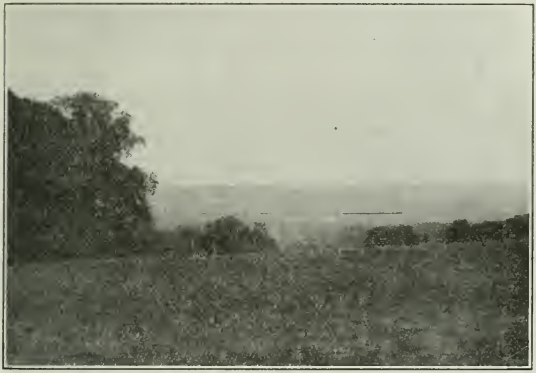


FIG. 6.

RESULTS.—The photographs of Figs. 5 and 6 are the photographs obtained at our first and second camera stations respectively. The optical centres have been obtained in the usual way by means of fiducial marks imposed upon the negatives at the moment of exposure. The horizon points have been found by a point in the distant landscape too feebly marked to be visible in the reproduced photographs, but perfectly visible in the negatives. The rule for determining the dip angle of the optical axis below the horizontal plane from these two points is simple, and may be taken to be known.* The instructions to the photographer were to give photograph Fig. 5 a dip angle (θ) of 5°, and photograph Fig. 6 a dip angle of 0°. The photographs, when measured up, show dip angles of $= 4^\circ : 25'$ and $= 0$ respectively. The camera had a focal length of 7·196 ins., so that the parameters of the two photographs were respectively 7·218 ins. and 7·196 ins. When mounted on the plotting board, photograph Fig 5. was placed with its horizon point at a distance of 7·218 ins. from the line of centres on the board, its optical centre being perpendicularly above the field centre of the photographic side of the board. These considerations settle the position of the photograph upon the plotting board and, incidentally, subject to modification, the scale of the plan to be plotted from it.

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* See p. 22 of *Generalised Linear Perspective.*

In the photograph Fig. 5, there are two beaconed points, the levels of which can be ascertained from the photograph itself. The points are indicated by the reference figures 1 and 2, and are positions, marked out by ranging poles, which are to serve as our second and third camera stations respectively. The ranging poles are spaced 5 ft. apart, and their levels below the horizon plane of the first camera station are given by the formula—

$$\text{Alt.} = \frac{F}{p} \quad \frac{B}{b} h \quad \dots\dots\dots\dots \quad (3)$$

Here Alt. is the altitude of the first camera station over the second and third stations respectively.

p = the parameter of the photograph.
F = focal length of the camera.
B = the space apart of the ranging poles used as beacons.
b = the space apart of the images of the ranging poles in the photograph.
h = the horizon distance of the beacon (feet of the ranging poles) in the photograph.

The following data suffice, therefore, to determine these levels in photograph No. 1 :—

p = 7·218 ins.
F = 7·196 ins.
$B_1 = 5$ ft. $= B_2$.
$b_1 = 0{\cdot}106$ ins. $b_2 = 0{\cdot}059$ ins.
$h_1 = 0{\cdot}615$ ins. $h_2 = 0{\cdot}46$ ins.

Hence we obtain by a mere slide rule computation :—

$$\text{Alt.} ({}_1) = \frac{7{\cdot}196 \times 5 \times 0{\cdot}615}{7{\cdot}218 \times 0{\cdot}106} \text{ ft.} = 28{\cdot}9 \text{ ft.} \dots\dots \quad (4)$$

$$\text{Alt.} ({}_2) = \frac{7{\cdot}196 \times 5 \times 0{\cdot}46}{7{\cdot}218 \times 0{\cdot}059} \text{ ft.} = 39{\cdot}0 \text{ ft.} \dots\dots \quad (5)$$

These levels, it will be observed, are ascertained from a single photograph, and do not need to be inferred from parallax.

This determination was verifiable by reference to photograph Fig. 6. Here only one camera station is visible ; it being the second of the two stations shown in Fig. 5.

The data for determining its level by equation (3) are given in the following summary :—

$p = 7\cdot196$ ins.
$F = 7\cdot196$ ins.
$B = 5$ ft.
$b = 0\cdot129$ ins.
$h = 0\cdot377$ ins.

Here, since $\frac{F}{p} = 1$, the equation is simplified into :—

$$\text{Alt.} = \frac{B}{b}\,h \quad \dots\dots\dots\dots \quad (6)$$

and we have—

$$\text{Alt.} = \frac{5 \times 0\cdot377}{0\cdot129}\ \text{ft.} = 14\cdot63\ \text{ft.} \quad \dots\dots\dots \quad (7)$$

If, now, we compare the results of (4) and (5) we have 39·0 – 28·9 = 10·1 ft. = the depth of the level of the third camera station below that of the second, the starting position being reckoned the first. Again, comparing this difference with the result of equation (7) we have 14·6 – 10·0 = 4·6 ft. for the height of the camera above the ground on which it rests. In other words, 4·63 ft. is left for the height of the camera stand. This varies from the actual height (4·58 ft.) by less than one inch. This small discrepancy is the closing error of a survey involving three independent contouring operations yielding 39·0 ft., 28·9 ft. and 14·8 ft. respectively, a total of 82·7 ft.To incur a closing error of 2 ins., amounting to 0·001 per cent. in levelling over 600 feet of slope is a matter for which no apology need be offered. It represents a very high degree of accuracy in the carrying out of topographical work.

Contours having thus been determined, the ground can be mapped from the photographs. The plotting of a plan from Fig. 5 is illustrated in Fig. 7, and, in view of the illustrations already given of the use of an hyperbola in plotting, the operation will be easily understood. There are seven points to be plotted at three different levels. They are as follows :—

(1) The second camera station—28·9 ft. below horizon plane.
(2) The third camera station—39·0 ft. below horizon plane.
(3) The copse in the middle distance.
(4, 5, 6 and 7) Four points on the two ridges defining the hollow seen in the foreground of the picture.

With regard to these four points, last mentioned, it is taken that they are, nearly enough for practical purposes, on the level of No. 1. The level of the copse will fall to be discussed in a later paragraph.

It is proposed to plot a plan from this photograph to the scale 1 : 1,000 (reproduced to the scale of 1 : 4,000).

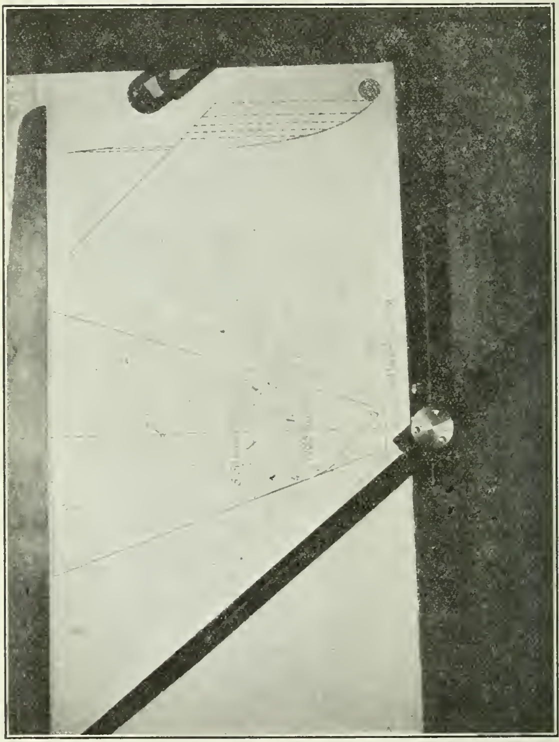

FIG. 7.

To deal first with points 1, 4, 5, 6 and 7. The level here is 28·9 ft., equal to 48·5 F. The normal hyperbola would therefore give a plan to the scale of 1 : 48·5, in which case the copse would stand nearly 18 ft. away from the first camera station ; that is to say, a long way off any possible plotting board. To produce a map to the 1 : 1,000 scale we must accordingly reduce the scale of the plan from that of the photograph in the ratio of 1 : 20·7

It is not necessary to inscribe upon the plotting board a large segment, as in Fig. 3, of the hyperbola which we propose to use, for a small segment will suffice for our actual requirements. The point at this level most distant from the parameter parallel, point No. 5 in the photograph, has the parameter distance of 6·88 ins. The nearest point is distant by 6·45 ins. The segment of the required hyberbola which extends between these limits is therefore all that we shall require. The dimensions of that segment are easily obtained from the model hyperbola (Fig. 4). That hyperbola is constructed for a photograph having a parameter of 10 in., and has its abscissæ reduced in the ratio of 1 : 20. The parameter of our photograph is 7·218 ft., and we propose a reduction of scale in the proportion of 1 : 20·7. The hyperbola which we require will therefore have abscissæ proportioned as 692 : 1,000 to those of the model hyperbola. The next point to be considered is the identification in the model curve of the segment in which we are interested. That presents no more difficulty than the last problem. We have only to express the above mentioned parameter distances in terms of the parameter and the segment is defined. Thus :—

$$\frac{6{\cdot}88}{7{\cdot}218} = 0{\cdot}95 \text{ and } \frac{6{\cdot}45}{7{\cdot}218} = 0{\cdot}89$$

The segment, therefore, with which we are concerned lies between the ordinates 0·95 and 0·89 in the model curve. Although a small segment of a large curve, this segment is of too deep curvature to be treated as a straight line. It will, therefore, be convenient to subdivide it into smaller segments. Multiplying these quantities so determined by 0·692 we obtain the abscissæ of the actual hyperbola which will serve to plot the points in question on the 1 : 1,000 scale.

In order to place this curve upon the plotting board recourse must be had to the mediating line already described in connexion with Fig. 3. But this mediating line need not be carried down to the parameter level itself. It will suffice to make it start from the lowest point of the photograph ; so saving space on the plotting board. The parameter distances with which we are concerned are identified on the scale imposed on the right hand side of the plotting board, and the points so found on the mediator line lie vertically over the corresponding points in the hyperbola. Verticals, let fall from these mediating points, will intersect the hyperbola, and by taking points in those verticals at the distances determined as above from the parameter parallel, the required points in the hyperbola are identified. They are connected by a smooth curve and our hyperbola is drawn. The points 1, 4, 5, 6 and 7 may now be plotted by its means by the method of plotting explained in connection with Fig. 3 The points correspondingly numbered on the plan are the result. The point marked 2 stands at a lower level, being as above shown, at a distance equal to 39·0 ft. (= 65·3 F.) below the horizon plane. The hyperbola by which it may be plotted has abscissæ in the proportion of $\frac{20 \times 65\cdot3 \times 0\cdot7218}{1{,}000} = 0\cdot94$ of those of the model hyperbola. But, inasmuch as in this case only one point falls to be plotted by this hyperbola, it is not worth while to draw it on the board. The arithmetical operations necessary for drawing any, even the shortest segment, would be two, whereas one of those computations suffices to place the given point on the plotting board without more ado. In this case, therefore, the arithmetical is less troublesome than the graphic solution.

There remains the copse to be plotted, but its level cannot be gauged by the comparison of the dimensions of the original with the dimensions of the image for the dimensions of the object are here unknown. Its level must be deduced from its parallax, and for this purpose recourse must be had to the second photograph, reproduced in Fig. 6. Two tree trunks in this copse have been selected for plotting, both appearing to stand on the crest of the farthest visible ridge in the picture. They may, therefore, be taken to be the nearest trees of the clump to the spectator, and to stand upon one and the same level. It will suffice here to illustrate the determination of level in such a case by contouring the more conspicuous of the two. In Fig. 5 it has an horizon distance of 0·448 ins. A very simple calculation shows that its distance in the plan from the plumb point of the camera station would be 116 ins.* The horizontal distance between the two camera stations is known from the photographer's log to be 330 ft. This quanity, divided by the 65·3, the altitude, in terms of focal length, of the first camera station above the third, gives 60·5 ins. as the reduced length of the stage or the length by which the distance of the second camera station is placed in front of the first upon the reference plane. Hence the distance of this point in the second photograph (Fig. 6) from the plumb point of the second camera station will be

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* See *Generalised Linear Perspective* page 5.

116 – 60·5 = 55·5 ins. Again, from this we obtain $p^2/55 \cdot 5$ ins. = 0·938 ins. for the horizon distance of this point in an hypothetical photograph taken from a position vertically above the second camera station at a height over it equal to the difference of level between the two stations.

The hypothesis may be illustrated by the diagram of Fig. 8. Here S_1 and S_2 (S_1 being an hypothetical position advanced so as to stand vertically over S_2) are the two camera stations; $h_1 \ldots h_1$ is the hypothetical horizon distance of the tree trunk in the hypothetical photograph on the assumption that it stands on the same level as the station S_2.

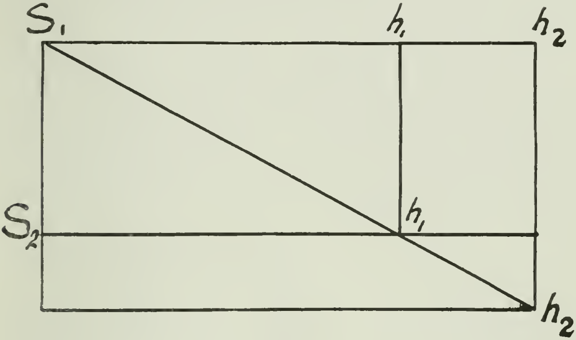

FIG. 8.

But the second photograph shows that it lies below that level, and at a distance equal to $(h_2 \ldots h_2) - (h_1 \ldots h_1)$ below it. We may, therefore, infer that the contour depth of the trunk below the horizon plane of the first photograph is equal to $\frac{h_1 + (h_2 - h_1)}{h_1} \times$ alt. The actual horizon distance of the tree trunk in the second photograph is 0·38 ins. Hence we have for the depth below the upper horizon plane

$$\frac{0 \cdot 94 + 0 \cdot 38}{0 \cdot 94} \times 65 \cdot 3 \text{ F} = 91 \cdot 7 \text{ F}.$$

Thus it appears that in the photograph of Fig. 5 the clump of trees appears on a scale of 1 : 92. To reduce this to a scale of 1 : 1,000 we must diminish it in the proportion of 1/10·9, and accordingly our working hyperbola will have to the model hyperbola the absciss ratio

$$X = \frac{20 \times 0 \cdot 7218}{10 \cdot 9} X_m = 1 \cdot 324$$

where X is the absciss of the working hyperbola and X_m the corresponding absciss in the model hyperbola.

A segment of the working hyperbola constructed on this basis is shown in the diagram of Fig. 7, and might be used to plot the trees of the copse. But it will be evident at a glance that the intersection of a vertical line with this very nearly vertical curve would be too uncertain for any but very rough work. In other words, the graphical method of plotting breaks down in practice when the plotting has to be done far in the background of the photograph. The arithmetical solution is, however, still available, and was, in fact, adopted, in plotting the two trees which at the point 3 in the plan represent the coppice.

It will now be asked what is the degree of accuracy obtainable by this method of surveying. The answer is furnished by the map of the surveyed area in Gatton Park. The two camera stations and the coppice are verifiable positions here, the camera stations having been measured off on the occasion and the coppice being shown on the O.S. map. The measurements so ascertained compare with the plan photographically made as follows :—

Distance from C. Station No. 1.

	Laid off by Telemeter.	Measured by Steel Tape.	Plan.
Camera Station No. 1 ...	330 ft.	Not taped	329 ft.
Camera Station No. 2 ...	615 ft.	610 ft.	617 ft.
	O.S. Map.		
Coppice	885–12 = 873 ft.		862 ft. to the selected tree.

With regard to the apparent discrepancy between the O.S. map and the plan deduced from our photographs of 11 ft., it should be explained that as the position of our camera does not, of course, appear on the O.S. map, the measurement was taken from the nearest mapped point—a gate which bars the adjacent road. The distance from our station to that gate was not actually measured, but has since been estimated at 12 ft. The estimate cannot be an over-estimate but may easily be a few feet short. It should further be remarked that this is a background position which would appear in two succeeding photographs of the series, and would be finally fixed by reference to them, especially by reference to the second which would show it in the foreground

As to the accuracy of our levelling carried out on the above described method, evidence has been adduced in the smallness of the closing error. But two more tests are available, and were applied, for we took all possible means of checking the work. There is, first, the plotting test. From the description above given of the method by which the plotting hyperbola is fitted to the photograph it will be evident that the success of the plotting depends entirely upon the accuracy of the preliminary contouring. Hence the plotting tests given above are equally tests of the levelling work, and, like the closing error, prove it to be of high quality. There remains the third test. Levelling by the ordinary method for comparison, and to this also we have had recourse. Mr. T. E. Goodall, who acted as our photographer on this occasion, is an experienced railway surveyor, and he and Col. Cole, who also was present, in the capacity of an interested and critical spectator, were asked to determine independently by means of the ordinary levelling operations the depth of the fall between the first and the third of our camera stations. Their result was reported to us as showing a fall of 34·99 ft. on the slope. Our measurement obtained from the photograph No. 1 was, as above given, 39·0 ft. The difference represents the height of our camera stand, which was ascertained by Mr. Goodall to be 4·54 ft. This, added to his result of 34·99 ft., gives a depth of 39·53 ft., so that the result of this test is just as satisfactory as the result of the others. If we estimate the difference as gradient on the slope traversed the two results agree within a half of one per cent.

There remain the questions of time and expense to be considered, and on these points the results of the Gatton Park test may be regarded as instructive. In the first place, there is the field work to be considered. When planning the Gatton Park expedition we provided for three experts—one being a junior surveyor in charge of the level. But it is now evident that we attached excessive importance to the level readings. Apart from verification tests, the only use which we made of the level was to identify an horizon point. The method of levelling by the camera itself herein described is now shown to be so accurate that an independent level can be almost dispensed with. A clinometer mounted on the camera or the camera stand will give all the required control in placing the camera. For the rest a camera properly calibrated will tell us all that we want to know about levels. In future, therefore, we shall require only one surveyor and one photographer as the necessary expert staff to carry out an expedition. The strength of the bearer staff must depend upon the exigencies of transport.

On the subject of time we are able to make an equally satisfactory report. Thus, comparing the levelling operations undertaken at Gatton Park, the levels of the two camera stations were photographically obtained by the use of a single photograph.

Obtained by the ordinary method by working with a dumpy level and staff, it required the setting up of the level in 10 different stations in succession to obtain the same result. Now the setting up of a camera is, for all practical purposes, the same operation as the setting up of a level, and takes no more time. The exposure of a sensitive plate is a much less troublesome operation than the taking of an observation on a surveyor's staff, and on the photographic plate the observation is automatically recorded and with infallible accuracy. The time in the field consumed in this one operation was by the photographic method only a small fraction of that consumed in ordinary topographical surveying by level and staff. But this comparison does not do full justice to the photograph. Mr. Goodall, in the course of his operation, had determined 14 levels, some available for the survey in hand, others necessary only to circumvent difficulties of the ground. But when the wealth of his record in this report is compared with the wealth of the photographic record, the difference is striking, even enormous. The photograph contains data from which any and every point can be contoured on which we think fit to place a beacon and every natural object which can be identified in a second photograph. Thus, our photograph served not only to contour the beaconed points 1 and 2, but also, when brought into comparison with the photograph of Fig. 6, to contour the unbeaconed trees of the coppice. In a word, any point which is marked by a beacon, though not otherwise recognisable, and any point, although not beaconed, which can be identified in two photographs, can be both contoured and plotted with accuracy. The advantage of the photographic record over the field book record in this respect is inestimable.

When it comes to a comparison of office work the advantage of the photographic record is seen in its fullness. There are no mistakes in the photographic record. Every entry can be relied upon implicitly. There is no possibility of confusion in connecting up levels with horizontal distances. In the field book record there is no necessary connection between the levelling and the chaining. It is a question of exact and accurate bookkeeping. But, in the photograph, plotting position and contour level are indissolubly connected. The surveyor who is interpreting the record has under his eyes the picture of the very thing with which he is dealing. It is comparatively seldom that the same man does both the field work and the plotting of the plan from the record. The advantage to the draughtsman of having before him a photograph of the country which he is mapping can hardly be overstated. The work under that condition is immeasurably easier than when lifeless figures only have to be dealt with.

Finally, it is to be remarked that contouring from photographs is a simple—extremely simple—arithmetical operation, involving no trigonometry and no mathematical equipment beyond a slide rule. Similarly, the plotting, carried out by the plotting board method, is in the main graphical, and when it is expedient to have recourse to mathematical solutions the mathematics is all of the simple equation and slide rule order. The most serious handicap that land surveying by photography suffers from at the present time, is that it has hitherto been discussed by very learned people as a branch of the doctrine of conic sections and transversals, and practised by very ingenious people as a development of the stereoscopic range finder. All this is superfluous learning and ingenuity. Contouring and plotting are essentially the same operation carried out, in the one case on the horizontal, the other on the vertical plane, and both are reducible to operations no more complicated than are involved in reducing a map from scale $1/m$ to scale $1/n$ by means of a pantagraph. The arithmetical operations illustrated in the foregoing paper cover the whole operation both of contouring and plotting in very undulating country, and they have involved nothing more serious than a slide rule computation. When engineers and land surveyors have realised the simplicity and efficiency of photographic land surveying they will confine the use of the theodolite and plane table to the class room, and save both time and money on the grand scale by substituting the photographic camera for both these instruments in the field.

DISCUSSION.

Mr. J. F. J. Reynolds, M.Inst.C.E., A.M.S.E., said with the present system of surveying, *i.e.*, with chain, level and theodolite, all information taken was " full size " and capable of being plotted to any scale required ; with photo records only, as suggested, the scale of the record was necessarily small.

For accurate records, the optical fitting of the camera would have to be very good and the register between lens and dry-plate perfect ; possibly the thickness of the emulsion on the plates used would have to be standardized. Focussing would have to be very accurate and personal error would come in here. Weather and light were factors that would have to be taken into account.

It appeared that a large number of beacons would be required, to pick up all points usual in a survey, perhaps 100 or more for one exposure. Holes and depressions in rough ground, not visible from the camera, could not be recorded. Long grass and crops would obscure the actual ground surface.

No doubt all above points could be met by a suitable camera and a large number of sights, which would be most valuable, more particularly for filling in contours, as required for Garden City sites, etc.

A photographic attachment to level or theodolite which, in addition to registering the view, would keep a permanent record of levels and bearings, would be most useful and might save booking time in the field, especially for tacheometer work, where the number of readings was necessarily great.

When the author suggested the use of the theodolite should be confined to the class-room, he forgot that one of the chief functions of this instrument was to set-out work " full size " in the field.

Lord Askwith said that as a very old friend of Mr. Gordon, he always followed his work with great interest. He was not prepared to speak of the technical points involved in the lecture, but in more general manner he did consider that important points had been brought forward. First there was the claim of less time having to be taken, and Mr. Gordon had claimed that it was but a fraction of the time ordinarily consumed, with practical elimination of the spirit level and theodolite. Secondly, less time implicated less staff time, and it was claimed also that less staff in numbers were required, and that alone, without other factors, meant less cost. From the public point of view those were very important considerations. But saving of time and cost were of little use unless there was accuracy. Accuracy was the true test of Mr. Gordon's proposals. If he were right and if the calculations which he said could be so easily done, could be so done, and produce an accurate result, surely many of those present and many interested in surveys could test his principles and his methods for themselves and ascertain for themselves whether or not photographic survey, carried out, not in a manner which had been previously used, with an overlay of mathematics and superfluity, but in a simple form easily done by a mathematician, was not a valuable addition, propounded by Mr. Gordon, to the methods employed in their profession.

As to plotting, it was claimed that the plotter could have all the factors at present put before him, with the addition of new interests or data, through a photograph, or rather two or more photographs, of the object he was desiring to plot. It was valuable, as the last speaker had said, that monotony should be relieved. Nothing was more important for the success of hard work ; and if the absence of mistakes was secured by a photographic record, office work would be less arduous and monotonous. He hoped that attention would be given to the whole plan, and that it would be carefully considered by them in the interests of their profession and science.

Capt. G. T. McCaw, Secretary, Air Survey Committee, said the method of surveying by photography was not new. As a surveyor he confined his remarks on the whole to its use in topography. 15 years ago he was more enthusiastic in its favour than he was now ; but experience, if it sometimes mitigated enthusiasm, brought one more into touch with reality.

The photographic method was first advocated by Laussedat, a French Colonel of Engineers, who was quickly followed by Dr. Deville, now Director-General of Surveys in Canada. Having the privilege of knowing Dr. Deville, he imagined that he would prefer to have his beautiful maps of the Yukon territory regarded as examples of applied science rather than mathematical abstractions.

Time did not permit of a discussion of the relative merits of survey by intersection from the extremities of wide bases and by the stereoscopic method : each had its advantages. The stereoscopic method was first, he believed, applied in South Africa by Mr. Fourcade. Dr. Deville about the same time wrote on the application of the Wheatstone stereoscope to survey, and almost simultaneously Pulfrich constructed a stereo-comparator, specially devised for measuring stereoscopic pairs. Vivian Thompson, a young Lieut. of the R.E., instructing at Chatham, found that working by the Pulfrich instrument was painfully tedious ; he accordingly devised the stereo-plotter. At the suggestion of Col. Sir Chas. Close, F.R.S., this instrument was used by the speaker in tropical country sufficiently hilly to warrant at least an experimental survey. In some respects it resembled the ingenious plotting board shown by Mr. Gordon, in that it was provided with an azimuth arm and distance bridge ; but the parallactic displacement was measured directly from a pair of plates and was not a parallax in depth along a traversed and levelled line as in the method advocated by Mr. Gordon. Distance, accordingly, was not measured by the use of an hyperbola drawn for the occasion, but was derived mechanically and immediately from the displacement.

The Thompson instrument inspired the improved stereo-autograph of von Orel, which had been brought to much perfection and had been a model for all later attempts in the same general direction, such as the autocartograph (German), the photocartograph (Italian) and the Stereotopomètre (French).

It was to be noted generally that photographic survey for topographical purposes was suitable only for certain kinds of country. For country with bold relief and with little timber, it was often found advantageous ; in flat or gently undulating country or even in greatly furrowed country where the texture was close, it had proved unsatisfactory ; and of course it was useless in dense forest. The greatest trouble was that which arose from the dead ground to which Mr. Reynolds had referred : the dead ground in phototopography varied from 25 per cent. on favourable to over 75 per cent. on unfavourable terrain. Moreover all the ground must be traversed, not only to fill in the lacunæ above mentioned, but also to obtain the names and other descriptive material without which no map would be complete.

Experience in the last few years in France, Austria and Italy suggested that for certain engineering purposes, in hilly country, it proved serviceable, the scales of such surveys being large. He considered that it might be found useful in the surveys of catchment areas for water supply and hydro-electric installations. It was worthy, also, of note that in France, Comdt. Vavon found that he obtained sufficient work in connection with engineering undertakings, railway and other, to keep in constant operation one of the expensive machines in which the plotting was made as nearly automatic—and as rapid—as seems humanly possible ; but he freely recognized that the greatest use of the method was confined almost wholly to large scale survey of small areas in hilly or mountainous country.

Mr. T. E. Goodall mentioned that in Johannesburg on the outbreak of the Boer War, the Intelligence Department had no Contour Map of Johannesburg. As he was conversant with the Mine Beacons, he had to make as rapidly as possible a plan for the Military of the approach and he did it by vertical angles on the Beacon. A few dozen plates taken in half a day by Mr. Gordon's system, it appeared to him would have saved no end of time and added to the accuracy of the projected plan. The Municipality alone consisted of 82 square miles.

Mr. A. Stewart Buckle, M.Inst.C.E., Vice-President, in proposing a hearty vote of thanks to Mr. Gordon for his valuable paper, stated that the system of making surveys by photography as described would be a great saving of time over the ordinary methods, and would probably avoid the errors so often found in preliminary surveys where the best line was not always the one chosen at first. He did not think that its advantages, for railways at any rate, would be great in England owing to the existence of the excellently well contoured Ordnance maps from which it was fairly easy to fix the proper location of a railway with comparatively little further survey work on the ground. But this island was only a small part of the world, and abroad the case was very different. In tropical forests such as he had worked in in Assam for many years, where the forest was so dense before the clearing was made one could never see the sun, it would not be possible to do any surveying by photography. He supposed that it was only intended to use the system for preliminary location, for in India the final survey included the actual pegging out of the railway, which, except for a few minor alterations, was (after checking) usually the actual line of pegs followed in construction.

He noticed in one case that the levels were found to check with actual levels taken with an instrument within 6 inches. He did not think that was good enough.

By these remarks he did not wish to detract from the value of the paper but only to point out its limitations.

THE AUTHOR'S REPLY.

Mr. Gordon, in reply, acknowledged the kind terms in which Lord Askwith had referred to his work and said Mr. Reynolds had spoken of the small scale of the photograph but therein lay a curious misconception. In the passage near the bottom of page 211, it was pointed out that the real difficulty was the reverse of what Mr. Reynolds supposed, for the scale of a photograph taken anywhere near the photographed area was simply enormous, so that powerful means of reduction had to be devised for transcribing from a photograph to a plan. The instance given in the passage in question was that of a photograph taken with a 7 in. lens from a height 50 ft. above the ground. Such a photograph, placed on the plotting board and plotted to its full scale, would give a plan to the scale of 6 ft. to a mile. It is this large scale of the photograph which secured the remarkable accuracy of maps made by photographic survey.

A second point which Mr. Reynolds supposed was a difficulty was that of focussing, which he said would introduce a personal error. This criticism also rested on a misconception. For accurate surveying a special camera with its lens fixed at the infinity focus was always used, and the focal length of the camera was determined with great accuracy, once for all. Thus, the camera used at Gatton had a focal length determined by calibration of 7·196 in. In this determination there might be an error in the third decimal place, but the determination might certainly be trusted to well within the second place. There was no adjustment or alteration of the focal length of a surveying camera when it had once been calibrated or, if exceptional circumstances should render any such adjustment necessary, the camera after readjustment would have to be recalibrated. The question of beaconing presented no real difficulty. In certain cases as, for example, if the depth of a grass-covered hollow had to be ascertained, it would be necessary to place some artificial mark for the purpose. But where any natural object, such as a coppice, or even a stone of recognisable form, could be identified in two successive photographs there was no need to have recourse to beacons. Such objects could be contoured by the parallacter method. The placing of a beacon, or to use a more familiar word—a mark, was the simplest operation in the world. The beacon which he—Mr. Gordon—used consisted simply of a ranging pole 6 ft. long, painted white, which was laid down in a horizontal position on the ground, or on a support of known height if it were necessary to raise it above the surface so as to be clear of grass, etc. The bottoms of ditches were levelled in the same way by 6 ft. rods which were supported above the bottom of the ditch on supports of recorded height, tall enough to bring the rod into the picture. The speaker felt himself indebted to Mr. Reynolds for these outspoken criticisms, which he hoped he had met, as they had afforded him the opportunity of proving to the Society that the system to which he called their attention had been carefully thought out.

The author thanked Captain McCaw for the kind expressions which he had used in respect of the construction of the plotting board, but with respect to the observation that the author's plotting board method was a stereoscopic one, he desired to make the distinction clear. It was indeed true that he could in his method deal, just as efficiently as Hugershoff could, with stereoscopic pictures, but it was important that he was not, like Hugershoff, confined to stereoscopic pictures, and the photographs of which he had been speaking were not stereoscopic at all. The distinction was of great importance. If pictures had to be combined in a stereoscope, or in a stereoscopic range finder, they must be taken in pairs and the two members of every pair must be taken under the same dip angle, and at equal distances from the photographed terrain. Therefore the cartautograph must be supplied with two photographs so paired from every station. That added greatly to the field work. Not only was the number of the photographs required for a given survey twice as great for the Hugershoff system, as for the author's, but the difficulty of getting suitable stations for the taking of two photographs of the same landscape on the same level, and 30 or 50 ft. apart, was itself a formidable handicap. On the other hand the method now under discussion was not subject to any such limitations. This method required only one photograph from each station, for the parallax observed was that which results from the travel forward of any given point from the background of photograph No. (n) into the foreground of a photograph No. $(n + 1)$. Thus he required to take only half as many photographs as by the cartautograph method. It did not matter to him how the level altered, or how the dip angle altered. His paper showed how easily difficulties arising from this cause were got over. He felt himself much indebted to Captain McCaw for having suggested a comparison which when followed up afforded him the opportunity of showing how much simpler, handier and more economical the parallacter method was than the stereoscopic method of deducing maps from photographs.

He much appreciated the kind words in which the Chairman had put the proposal of a vote of thanks before the meeting, but he had challenged him on the subject of the discrepancy of 6 ins. in contouring the level of station No. 3 from station No. 1 ; between the photographic determination and the result reached by Mr. Goodall and Col. Cole, which the Chairman regarded as unsatisfactory. The author suggested that there were two answers ; the first was the very direct answer which results from the discussion of this particular point in the passage above referred to. It was there shown that when the length of the slope, as well as the depth of the fall, was taken into account and the comparison was made in terms of gradient, the discrepancy amounted to less than one half per cent.

After consultation with some of his surveyor friends he came to the conclusion that it was not worth while to pursue the discussion of that matter further than that. But since the point had been raised that evening, it was no doubt worth while to draw attention to the fact that the photographic determination was probably the more trustworthy of the two, because in the first place that photographic level was made the basis of the plotting operation referred to at page 215 where telemeter and plan agreed to 2 in. in 600 ft., a result not possible if there had been any serious error in the levelling. A confirmatory reason was found in the circumstance mentioned in the paper that through the failure of a contractor they had found themselves short of a tower ladder which was to have been used as a surveying staff. The consequence was that they were without a proper surveying staff, and were obliged to improvise one out of a pair of ranging rods lashed together. The graduation of such an improvised staff was not in the nature of things unimpeachable ; but having this result, so reached, brought to his knowledge he thought it fair to place it for what it was worth before the Society.

N.B.—Readers interested in this subject may like to see paper by Mr. Bridges Lee on " The Photographic Camera as an Aid to Exploration, Record and Measurement " at page 16 of 1903-4 Transactions of the Civil and Mechanical Engineers' Society.

ANNUAL GENERAL MEETING.

The Fourteenth Annual General Meeting of the Society was held in the offices of the Society, 17, Victoria Street, S.W. 1, on Monday, December 10th, 1923, at 6 p.m., the Vice-President, Mr. G. A. Becks, being in the Chair.

The notice convening the meeting was read.

The Secretary read the Report of the Scrutineers on the result of the Postal Ballot for the election of the Council and officers for the year 1924. (See page 233.)

The Report of the Council for the year 1923 was read and adopted.

Messrs. Begbie, Robinson, Cox & Knight, Chartered Accountants, were re-elected as the auditors of the Society for the ensuing year.

A vote of thanks was accorded to the Scrutineers, Messrs. S. H. Marshall and P. W. W. Pope, for their services.

A vote of thanks having been accorded to Mr. Becks for taking the Chair during the past year, owing to the illness of the President, the meeting closed at 6.32 p.m.

REPORT OF THE COUNCIL FOR THE YEAR 1923.

In presenting their Fourteenth Annual Report of the Incorporated Societies, the Council have to state that the membership at this date is as follows :—

Hon. Fellows	21
Fellows	39
Members	282
Associate Members	214
Associates	66
Total	622

and that 28 Corporate Members and Associates were elected during the year 1923.

The following are the Associated Societies :—

Battersea Polytechnic Engineering Society.
Birmingham Association of Mechanical Engineers.
Birmingham University Engineering Society.
Crystal Palace Engineering Society.
Derby Society of Engineers.
Gloucestershire Engineering Society.
The Polytechnic (Regent Street) Engineering Society.
Queen's University (Belfast) Engineering Society.
Stoke-on-Trent Association of Engineers.
Wolverhampton & District Engineering Society.

The combined membership of these societies and our own is about 2,350. Under Clause 6 of the Regulations for the Association of Engineering Societies the members of these societies are entitled, on payment of a small annual subscription, to receive post free the journal of the Society. A number of members have availed themselves of this arrangement during the past year.

The Council much regret to record the deaths of the following during the year :—

Fellow.

A. T. WALMISLEY.

Members.

G. D'ALMEIDA.
H. E. ANDERSON.
E. W. A. CARTER.
H. A. FLINN.
BARON H. T. H. SICCAMA.
J. W. WHITE.

Associate Members.

W. H. ANDERSON.
A. EDWARDS.
J. RANDALL.
M. R. SETHI.

MEETINGS AND VISITS.

During the year seven Ordinary Meetings, eight meetings of the Council, and fourteen meetings of various Committees have been held.

The following visits to works were made by members and their friends :—

June 20th, Works of Messrs. Bryant & May, Ltd., Fairfield Works, Bow, E. 3.

July 11th, Works of Messrs. J. Lyons & Co., Ltd., Greenford, Middlesex.

July 30th—August 4th, the Royal Sanitary Institute Congress, which was held at Hull, was attended by Mr. E. F. Spurrell (Member of Council) on behalf of the Society, who reports that the Congress was extremely interesting and instructive.

September 4th, International Shipping, Engineering and Machinery Exhibition, Olympia.

September 19th, Construction of British Empire Exhibition, Wembley.

PAPERS AND PREMIUMS.

The following papers have been contributed during the year for discussion at meetings or for publication in the JOURNAL :—

"Practical Notes on Inspection," by A. COLLIS-BROWN, A.M.S.E.

"The Physical Properties of Clay" (*fifth* paper) and "The Dynamics of Pile Driving," by A. S. E. ACKERMANN, B.Sc. (Engineering), M.Cons.E., A.M.I.C.E.

"The Work of the Labour Corps in France during the War, with particular reference to the 178th Labour Co." by T. EXLEY-FISHER, M.S.E., P.A.S.I., A.M.Inst.M. & Cy.E.

"The Pneumatic Handling of Petrol and other Inflammable Liquids," by P. MAUCLERE, M.Soc.Ing.Civ. (France).

"The Impact of Imperfectly Elastic Bodies, with particular reference to the Effect of the Hammer Blow in Pile Driving," by A. HILEY, M.I.N.A., A.M.I.C.E.

"A New entirely Automatic Machine for Mass Production of Glass Bottles," by A. FERGUSON, A.S.E.

"Lubrication," by WILLIAM LEE, Chief Chemist of Silvertown Lubricants, Ltd.

"Railway Surveying by Photography," by J. W. GORDON, K.C.

The thanks of the Society are tendered to all authors of papers, and Premiums have been awarded as follows :—

The President's Gold Medal to Mr. J. W. GORDON.

The Bessemer Premium (value £5 5s. 0d.) to Mr. P. MAUCLERE.

The Nursey Premium (value £3 3s. 0d.) to Mr. A. HILEY.

The Bernays Premium (value £3 3s. 0d.) to Mr. A. FERGUSON.

A Society Premium (value £3 3s. 0d.) to Mr. A. S. E. ACKERMANN.

The Clarke Premium (value £5 5s. 0d.) to Mr. R. C. HILL, A.M.S.E., of the Gloucestershire Engineering Society, for his paper on " Work beneath the Waves."

The Geen Premium (value £5 5s. 0d.) to Mr. H. F. JONES, of the Crystal Palace Engineering Society, for his paper on " Boilers."

COUNCIL AND OFFICERS FOR 1924.

The result of the Postal Ballot for the election of Council and Hon. Officers for the year 1924 was as follows :—

As President : G. A. BECKS.

As Vice-Presidents : A. S. BUCKLE, G. O. CASE, D. C. FIDLER.

As Members of Council : W. J. HADFIELD, F. PURTON, C. CONNOR, H. C. ADAMS, E. F. SPURRELL, H. E. BERGMAN, A. K. DODDS, Prof. F. H. HUMMEL, C. H. J. CLAYTON.

As Members of Council from the Class of Associate Members : J. F. J. REYNOLDS, WM. HOLTTUM.

As Hon. Secretary and Hon. Treasurer : C. T. WALROND.

The thanks of the Society are due to Messrs. S. H. Marshall and P. W. W. Pope, the Scrutineers of the Ballot Lists.

APPOINTMENTS REGISTER.

The Council wish to remind members of the important work done by means of the Appointments Register (especially do they desire to call the attention of employers to this register) as, unfortunately, owing to present circumstances, there are more names than usual of well-qualified engineers on this register, and the hope is expressed that members will utilise the Register both to their own advantage and that of the members needing appointments. The benefit to the employer is that he saves the cost of advertisements, saves the labour of going through literally hundreds of applications, most of which are from unsuitable men, and saves the delay of waiting for the advertisement to appear. Usually a communication to the Secretary will ensure applications from some four or five suitable candidates within 36 hours. The exact requirements and the approximate salary should always be mentioned when communicating with the Secretary.

NEW MEMBERS.

Another important matter, which of necessity devolves chiefly on the members, is that of proposing suitable candidates for membership. The need for all qualified engineers to belong to one or more professional societies is well recognised, and full particulars of such benefits, application forms, etc., may be had from the Secretary.

INDEX TO TRANSACTIONS, 1910-23.

The date following each title indicates the year of publication, and the page reference is to the volume of Transactions for that year.

PAGE

Abattoirs (*see Slaughter*).
Accounts, Engineering. H. McFarland Davis ... 250
Accretion at Estuary Harbours on the South Coast of England. Gerald O. Case, 1913 ... 205
Adventures, Great Engineering. E. Cressy, 1920 ... 133
Airship R. 34, The Atlantic Cruise of H.M. E. E. Turner, 1922 ... 233
Airship R. 36, Visit to Inchinnan Aerodrome to View. W. R. Taylor, 1921 ... 131
Annual General Meeting, 1910 ... 292
——— 1911 ... 408
——— 1912 ... 343
——— 1913 ... 277
——— 1914 ... 344
——— 1915 ... 283
——— 1916 ... 271
——— 1917 ... 357
——— 1918 ... 215
——— 1919 ... 315
——— 1920 ... 311
——— 1921 ... 249
——— 1922 ... 289
——— 1923 ... 230
Artillery during the War, The Development of. Capt. M. E. de Jarny, 1919 ... 221
——— from the Scientific and Engineering Point of View. W. S. Bamford, 1921 ... 141
Assessment of Engineering Undertakings, The. W. G. Cooke, 1920 113
Attraction, Law of, for Molecular Force. Dr. Herbert Chatley, 1919 192
Axles of Railway Wagons. H. Kelway-Bamber, 1918 ... 189
Balance Sheet and Accounts, 1911 ... 114
——— 1912 ... 31
——— 1913 ... 65
——— 1914 ... 56
——— 1915 ... 46
——— 1916 ... 96
——— 1917 ... 248
——— 1918 ... 98
——— 1919 ... 158
——— 1920 ... 166
——— 1921 ... 250
——— 1922 ... 71
——— 1923 ... 115
Ball Bearings. A. Marshall Arter, 1917 ... 157
Blackpool Sea Coast Defence Works. H. Banks, 1920 ... 284
Bottles, A New entirely Automatic Machine for Mass Production of Glass. A. Ferguson, 1923 ... 147
Bridge Foundations in the East and the Sittang Railway Bridge, Burma Railways. A. S. Buckle, 1914 ... 251

PAGE

'BUS *v.* TRAM Controversy. W. Yorath Lewis, 1913 20

BY-PRODUCT Problem, A Survey of the Power. T. Roland Wollaston, 1918 65

CARTRIDGE, Uses of the Hydraulic Mining. James Tonge, 1914 ... 285

CHIMNEYS, The Design of Tall. Henry Adams, 1911 363

CLAY, EXPERIMENTS with, in its Relation to Piles. Alfred S. E. Ackermann, 1919 37

CLAY, The Lateral and Vertical Pressure Effect of Piles in, H. R. Lordly, 1920 171

CLAY, The Physical Properties of. Alfred S. E. Ackermann, 1920... 196

CLAY, The Physical Properties of. Alfred S. E. Ackermann, 1921...87, 173

CLAY, The Physical Properties of. Alfred S. E. Ackermann, 1922... 151

CLAY, The Physical Properties of, and the Dynamics of Pile Driving. A. S. E. Ackermann. 1923 ... ...25, 121

CLAY-MUD, The Physical Properties of. Dr. H. Chatley, 1922 ... 133

COAL, A Survey of the Power By-Product Problem. T. Roland Wollaston, 1918 65

COAL and its By-Products. J. R. L. Allott, 1921 157

COAL-FIELD, The South Eastern. B. L. Rigden, 1913 7

COAL TUBS. Prof. H. Adams, 1922 200

COAST PROTECTION (See *Accretion*).

COAST PROTECTION, The Winning of Tidal Lands in British Guiana. G. O. Case, 1921 177

COHESION. Dr. H. Chatley, 1921 135

COLONIES, as a field for Engineer work, (The). H. Conradi, 1911 ... 218

CONCRETE and Reinforced Concrete. H. M. Wilson, 1916 ... 139

——— Mixtures for Ferro-Concrete Work. T. J. Gueritte, 1918 33

CONCRETE, Fractures in. H. Bentham, 1922... 77

CONCRETE, The Action of Sea-Water on. Prof. E. R. Matthews, 1920 ... ... 75, 109, 157

CONCRETE, Waterproofing. H. S. Bonsor, 1922 70

CORROSION (See *Iron*).

COUNCIL, Report of, 1910 293

——— 1911 409

——— 1912 344

——— 1913 278

——— 1914 345

——— 1915 284

——— 1916 272

——— 1917 358

——— 1918 216

——— 1919 316

——— 1920 312

——— 1921 255

——— 1922 290

——— 1923 231

DESIGN of Continuous Beams, The. Ewart S. Andrews, 1916 ... 161

" " " in Ferro-Concrete. H. Brodick ... 199

DINNER, Amalgamation, 1910 1

——— 1911 7

——— 1911 197

DRAINAGE, The Economics of Arterial Land. C. H. J. Clayton, 1922 205

DRAWING OFFICE Organization. F. G. Woollard, 1911 231

ELECTRICAL PLANT, The Testing of Small. Dr. C. V. Drysdale, 1922 30, 93

ELECTRICAL Transmission of Power for Marine Transportation. W. P. Durtnall, 1912 267

——— Trolley vehicle system of railless traction. Henry C. Adams, 1912 35

PAGE

Electricity from the Wind. A. H. Allen, 1910... ... ... 7, 19
Empire Development, Engineers and. C. R. Enock, 1910... 165, 177, 193
Energy from the Sun, The Utilization of. A. S. E. Ackermann, 1914 81
——— 1915 177
Engineering and Scientific Research. J. A. Fleming, 1916 ... 101
——— Practice, Some Modern, in America. R. W. A. Brewer, 1921 31
——— Troubles in Africa and their Solutions, Some. G. A. Becks, 1910 197
Engines, Two-stroke Cycle. R. W. A. Brewer, 1911 303
Esperanto, An International Language for Engineers. T. J. Gueritte, 1914 59
Explosives, Modern. Prof. J. Young, 1919 109
Ferro-Concrete (See *Reinforced Concrete*).
Flood Prevention Works at Troon, Ayrshire. Prof. E. R. Matthews, 1920 75
Fuel Economy. A. E. A. Edwards, 1920 140
Gas, Petrol Air. E. Scott-Snell, 1911 73
Gas Works, The re-construction of a country. A. E. Whitcher, 1915 223
Gold Medal, Recipients of President's from its Institution to date 74
Goods Clearing House System and Machinery Explained, The. Lord Headley, 1917 195
Harbours (See *Accretion*).
Heating and Ventilating Private Dwelling Houses. C. T. Alfred Hanssen, 1916 189
Heating and Ventilation. A. H. Barker, 1915 115
High Tensile Steel *versus* Mild Steel for Reinforcing Concrete. A. W. Shelf, 1917 131
Highways. C. H. Cooper, 1913 171
Hydraulic Separation, Studies in. J. M. Draper, 1920 ... 127
India, Irrigation in. R. H. Cunningham, 1914 205
Inspection of Materials (See *Testing*).
Inspection, Practical Notes on. A. Collis-Brown, 1923 5
Intermittency : its effect in limiting electric traction for city and surburban passenger transport. Wm. Yorath Lewis, 1912 ... 121
Iron, Corrosion and Rusting of. Eric K. Rideal, 1913 239
Irrigation in India. R. H. Cunningham, 1914 205
Labour Corps in France during the War, with particular Reference to the 178th Labour Co., The Work of the. T. Exley-Fisher, 1923 71
Language, Esperanto for Engineers. T. J. Gueritte, 1914 ... 59
Law and Engineering, Some points of contact. S. G. Turner, 1915 195
Life Guards for Motor Vehicles. H. Conradi, 1916 7
Life in a British Internment Camp, 1917 287
Lighthouse Design and Construction. L. S. Spiro, 1915 ... 7
Lighting, Electric, of steam driven trains. E. Kilburn Scott, 1914 1
Ligno-Concrete. Gerald O. Case, 1912 83
Load, The Dynamic Increment of a uniformly distributed. Herbert Chatley, 1914 221
Locomotives of the L. & N.W.Rly. C. F. Moore, 1922 120
Lubrication. Wm. Lee, 1923 175
Machinery, Inspection and testing of Engineering Materials and. C. W. V. Biggs, 1910 133
Marine Transportation, Generation and Electrical transmission of power for. W. P. Durtnall, 1912 267
Materials (See *Machinery*).
Members, List of 137
Mineral Requirements of the British Iron and Steel Industries, The. Professor W. G. Fearnsides, 1917 1

PAGE

MINERAL Resources of the British Empire with regard to the Production of Non-Ferrous Industrial Metals, The. C. Gilbert Cullis, 1916 215
MINING, Uses of the Hydraulic Cartridge. James Tonge, 1914 ... 285
MODERN Coal and Coke Handling Machinery: as used in the Manufacture of Gas. J. E. Lister, 1916 65
MODERN Shipbuilding and Economy of Material. J. W. Isherwood, 1918 103
MODULUS of Elasticity of thin flexible strips. F. H. Hummel, 1912 209
MOTOR Vehicles, Running costs of. R. W. A. Brewer, 1915... ... 51
MURMANSK and Archangel Districts, Some Notes on the. B. L. Rigden, 1920 39
NITROGEN Products made with the aid of Electric Power. E. Kilburn Scott, 1911 9
NOTES on Railway High-Capacity Wagon Wheel Axles. H. Kelway-Bamber, 1918 189
OBSTACLES to Post-War Trade. Sir Richard Cooper, 1918 ... 169
ORGANIZATION, Drawing Office. F. G. Woollard, 1911 231
PERMANENT WAY on Railways, The Mechanical Installation and Upkeep of. T. J. Gueritte, 1911 249
PETROL Air-Gas. E. Scott-Snell, 1911... 73
PETROL and other Inflammable Liquids, The Pneumatic Handling of. P. Mauclere, 1923 87
PILE-DRIVING, The Dynamics of. A. S. E. Ackermann, 1923 ... 25
——— The Impact of Imperfectly Elastic Bodies, with particular reference to the effect of the Hammer Blow in. A. Hiley, 1923 125
PIT-PROPS AND HEAD TREES, The Strength of. Prof. Henry Adams, 1919 213
POLLUTION, Subterranean erosion of water-bearing strata in relation to. Spencer Sills, 1912 7
POSSIBILITIES in Engineering. L. S. Spiro, 1913 163
POST-WAR Trade, Obstacles to. Sir Richard Cooper, 1918... ... 169
POWER, Tidal Waters as a source of. C. A. Battiscombe, 1913 115
PRACTICAL Roadwork in the United Kingdom. E. G. Wilson, 1917 275
PRESIDENTIAL ADDRESSES. Diogo A. Symons, 1910 25
——— F. G. Bloyd, 1911 37
——— John Kennedy, 1912 21
——— Arthur Valon, 1913 69
——— H. C. H. Shenton, 1914 30
——— Norman Scorgie, 1915 24
——— Percy Griffith, 1916 23
——— Henry C. Adams, 1917 115
——— W. B. Esson, 1918 9
——— W. Noble Twelvetrees, 1919 8
——— Burnard Geen, 1920 10
——— The Rt. Hon. Lord Headley, 1921 7
——— T. J. Gueritte, 1922 7
PROFESSIONAL Topics, Current. Henry C. Adams, 1910... ... 203
PUMPS, Air-lift. J. A. Coombs, 1922 20
PUMPS, Testing Centrifugal. F. H. Hummel, 1913 149
RAIL PLATEWAYS. G. Noble Fell, 1912 199
RAILLESS Traction, The Trolley vehicle system of. Henry C. Adams, 1912 35
RAILWAY COY. (R.E.) in France and Belgium during the War, Some Engineering Work done by the 227th. R. H. Cunningham, 1290 43
RAILWAY Engineering in China, Notes on. G. L. B. Newmarch, 1917 255

PAGE

Railway, The Promotion and Construction of the London and Birmingham. F. G. Bloyd, 1911 ... 200
Railways, High-Speed. E. W. Chalmers Kearney, 1917 ... 307
Railways, The Mechanical Installation and Upkeep of Permanent Way on. T. J. Gueritte, 1911 ... 249
——— Safer, Quicker and Cheaper. C. R. Enock, 1911 ... 267
Reinforced Concrete retaining walls. E. R. Matthews, 1910 ... 181
——— Test deflections in. P. J. Waldram, 1912 ... 311
Report of Council, 1910 ... 293
——— 1911 ... 409
——— 1912 ... 344
——— 1913 ... 278
——— 1914 ... 345
——— 1915 ... 284
——— 1916 ... 272
——— 1917 ... 358
——— 1918 ... 216
——— 1919 ... 316
——— 1920 ... 312
——— 1921 ... 255
——— 1922 ... 290
——— 1923 ... 231
Reservoirs, A Short Paper on. Basil C. Light, 1917 ... 261
Resettlement of Officers in Civil Life. A. Stewart Buckle, 1919
Retaining Walls, Reinforced Concrete. E. R. Matthews, 1910... 181
Rivers and Waterways, National Control of. Reginald Brown, 1913 ... 155
Roads Development Act, 1909, The Working of. Reginald Brown, 185
1910 ... 265
Roads, Main; Past and Present. F. Grove, 1915 ... 81
——— Up-to-date. R. O. Wynne-Roberts, 1910 ... 101
Rolling, Resistance to. Herbert Chatley, 1912 ... 179
Roll of Honour, 1917 ... 361
Rusting (See *Iron*).
Sewage and its Precipitation: Facts and Fallacies from Laboratory and Practical Tests. Reginald Brown, 1916 ... 37
——— and its Precipitation: Further Experiments. Reginald Brown, 1917 ... 289
Sewage Disposal Ideals. W. C. Easdale, 1910 ... 43
Sewer from Battersea to Deptford, Construction of a L.C.C. low-level main. J. P. Harris, 1912 ... 223
Sewer Ventilation and Health. William Brown, 1919 ... 247
Sewerage and Sewage Disposal Works, Northwich. W. M. Beckett, 1921 ... 223
Shipbuilding and Economy of Material, Modern. J. W. Isherwood, 1918 ... 103
Slaughter of Animals, Mechanical Appliances for the painless. S. M. Dodington, 1914 ... 309
Slaughter-Houses, Public. S. M. Dodington, 1910 ... 229
Solar Energy, The Utilization of. A. S. E. Ackermann, 1914 81
——— 1915 ... 177
Status Prize Essay. Wm. Ransom, 1913 ... 91
Steam Control Device, A Simple Low Pressure. J. W. Smith, 1920 157
Steel, Heat Treatment of. C. O. Bannister, 1919 ... 163
Sun, Utilization of Energy from the. A. S. E. Ackermann, 1914... 81
——— 1915 ... 177
Surveying by Photography, Railway. J. W. Gordon, 1923 ... 197

PAGE
Surveys, Reconnaissance. L. S. Spiro, 1913 145
Testing and Inspection of Engineering Materials and Machinery. C. W. V. Biggs, 1910 133
Tidal Lands, The Winning of, in British Guiana. G. O. Case, 1921 177
Tides, as a source of Power. C. A. Battiscombe, 1913 115
Town-planning from an Engineering standpoint. E. R. Matthews, 1912 235
Traction Intermittency; its effect in limiting. Wm. Yorath Lewis, 1912 121
——— Trolley vehicle system of railless. Henry C. Adams, 1912 35
Trade Unionism as applied to Professions. A. B. Howes, 1914 ... 229
Traffic Problem, The London. W. Yorath Lewis, 1913... ... 20
Trains, Electric lighting of steam-driven. E. Kilburn Scott, 1914 1
Transport, Mechanical in the War. Capt. Richard Twelvetrees, 1919 279
Turbines (See *Water Power*).
Turbines, Extraction. C. H. Naylor, 1921 208
Tyre, The Motor Car Pneumatic. J. C. Ferguson, 1921 60
Vacuum Railways, High-Speed Land and Sea. Arthur Oates, 1917 233
Vehicles, Running Cost of Motor. R. W. A. Brewer, 1915 ... 51
Ventilation and Heating. A. H. Barker, 1915 115
Versailles, The Unknown. T. J. Gueritte, 1919 190
Visits, 1923 ... ... 119 & 143
Wagon Wheel Axles, Notes on. H. Kelway-Bamber, 1918 ... 189
War on and under the Sea. Edwin Hall, 1918 153
Water bearing strata in relation to pollution, Subterranean Erosion of. Spencer Sills, 1912 7
Water Conservancy, The Administrative Aspect of. W. R. Baldwin-Wiseman, 1911 120
Water Power, The Modern Development of. A. Steiger, 1915 233
——— Supplies, Protection of. H. C. H. Shenton, 1911 ... 157
——— Supplies, Public. Percy Griffith, 1915 157
——— Supply of Greater New York, Notes on. William T. Taylor, 1914 ... ... 167 & 241
Waterworks, Moulmein. P. G. Scott, 1910 79
Wave Power Transmission. W. Dinwoodie, 1922 266

Note.—A complete index to the Transactions of the old Society of Engineers will be found in the last volume (1909) published by that Society, and the volumes of Transactions of the Civil and Mechanical Engineers' Society are also indexed.

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1
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